STEP 11

ITHACO

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INSTRUCTION AND MAINTENANCE MANUAL

ITHACO 4110 SERIES

VARIABLE ELECTRONIC FILTERS

APRIL, 1979

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SECTION 1

1.0 GENERAL DESCRIPTION

1.1 DESCRIPTION

The 4110 Series Variable Electronic Filters can operate as a band-pass, high-pass or DC coupled low-pass filter. Precise filter characteristics permit close tracking of amplitude and phase, and the combination of large signal handling capability and low self-noise provides a wide dynamic range. 1/3 octave frequency steps (approximately 1/10 decade) provide a 2 dB resolution.

Independently tuned high-pass and low-pass sections are cascaded to form a band-pass filter. Setting the high-pass section to OUT permits the filter to operate as a DC coupled low-pass filter. Each section possesses maximal flat filter characteristics (4 pole Butterworth) with 24 dB/octave terminal attenuation slope (80 dB/decade).

Precision filter characteristics permit phase and amplitude tracking between filters with the same setting. Filter cutoff, bandwidth, noise bandwidth, and gain are precisely controlled and specified for each setting. 1/3 octave filter settings provide 10 equally space settings on a logarithmic scale in each decade and permit the 4110 Series filters to operate as a 2/3 octave or as one octave filter set.

The filters have high input and low output impedance, and the compact modular construction permits 7 filters to operate in one 19" rack mounting case.

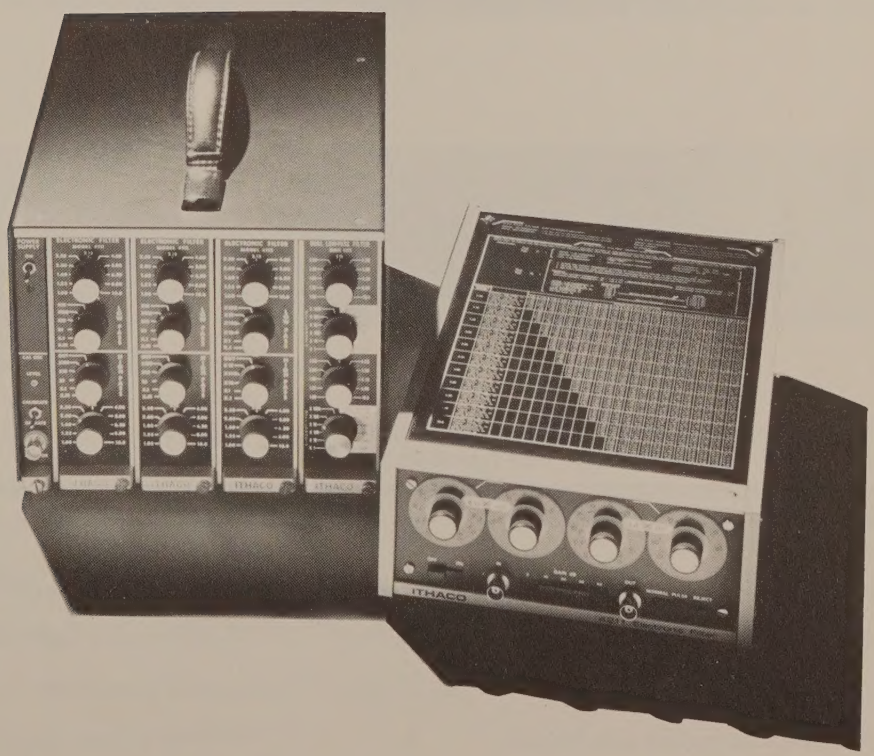
1.2 OPTIONS

1.2.1 XLR OPTION

A 5 pin XLR connector is added on the rear of the filter. This option is used when operating with a remote preamplifier.

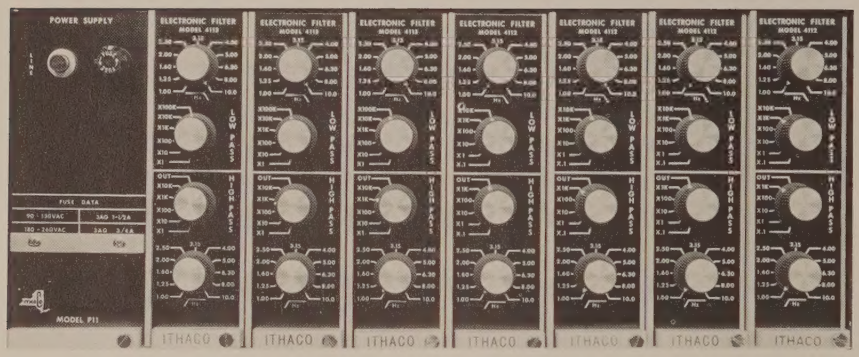
1.3 SPECIFICATIONS

ITHACO
Variable electronic filters



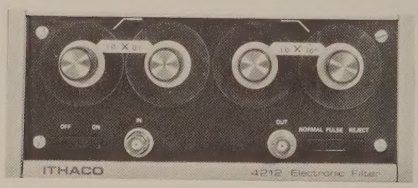
IPS 104

variable electronic filters



4110 series filters

4120A series filters



4210 series filters

4302 dual filter

SPECIFICATIONS ARE SUBJECT TO CHANGE WITHOUT NOTICE. COPIES OF ITHACO'S 12 MONTH WARRANTY AVAILABLE UPON REQUEST. SEE PRICE LIST FOR CURRENT PRICES.

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FREQUENCY RESOLUTION	MODES	FREQUENCY RANGE *	SLOPE	CATALOG PAGE
1/10 Decade Steps	LP, HP, BP Butterworth	.01 Hz → 1 MHz (6 decades per model)	24 dB/octave	6
1/10 Decade Steps	Dual LP Butterworth	.1 Hz → 1 MHz (6 decades per model)	24 dB/octave	7
1/10 Decade Steps	LP, HP, BP, BR Butterworth Bessel	.01 Hz → 1 MHz (6 decades per model)	24 dB/octave	9 – 10
1/10 Decade Steps	DUAL LP, DUAL HP, BP Butterworth Bessel	10 Hz → 1 MHz (5 decades)	24 dB/octave (48 dB/octave Series Connected)	12 – 13

* All models may be used as DC coupled low pass filters

related publications

IAN–101	*"Phase and Amplitude Response of Variable Electronic Filters"*
IAN–102	*"Measuring Noise Spectra With Variable Electronic Filters"*
IPS–109	*"AC Instrumentation Amplifiers – 450 Series"*
IPS–112	*"Low Noise Preamplifiers"*

about ITHACO filters

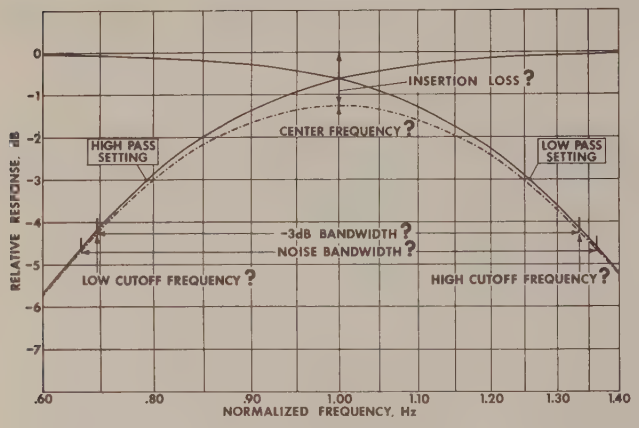


Figure 1 Bandpass Filter

THE FRONT PANEL – WHAT DOES IT TELL YOU?

The front panel frequency setting of a filter can tell you only one thing––the –3 dB frequency of the filter section with which it is associated. For many applications this is not enough. For example:

- What are the –3 dB frequencies and the insertion loss of bandpass filters when the high and low-pass sections are close enough that they cannot be regarded as independent filters? (Figure 1)
- What is the center frequency of a bandpass filter with independent high and low-pass sections? (Figure 1)
- What is the noise bandwidth of a bandpass filter? (not the same as the –3 dB bandwidth.) (Figure 1)
- What is the attenuation at frequencies other than the –3 dB point? What is the phase shift at any frequency? (Figures 2 and 3)
- In pulse modes, what is the step response characteristic of the filter for various frequency settings? (Figure 4)

ITHACO PROVIDES THIS INFORMATION BY PRINTING IT ON TOP OF THE 4210 SERIES FILTERS.

- Model 4210 Series 1/10 decade filters provide the following data for all filter settings: (see Page 11)
  - Upper –3 dB frequency
  - Lower –3 dB frequency
  - Center frequency
  - –3 dB bandwidth
  - Noise bandwidth
  - Insertion Loss (filter gain)

RESOLUTION AND ACCURACY

Continuously tunable filters are inherently qualitative instruments with, at best, 5% accuracy, poor reproducibility of settings, and poor frequency and phase shift characteristics. If a filter must be set with high resolution, there is a strong implication that the user wants to know accurately where the cutoff frequency is. This cannot be determined from the dial settings of a continuously tunable filter –– and must therefore be measured; a time consuming and expensive process.

ITHACO solves this by offering filters with switch-selectable frequency settings. These filters use the internationally accepted 1/10 decade frequency step (10 steps per decade on a logarithmic scale). This permits operation with octave, decade, and other convenient bandpass settings, and provides sufficient frequency resolution for general laboratory and data acquisition applications. These filters have the advantage of compactness, ease of use, and freedom from operator error.

Standard accuracy of the 4110, 4120A and 4210 Series Filters is ±1% in frequency, ±2° in phase, and ±.1 dB insertion loss––all at least twice as good as the best competitive filters.

The Model 4302 Dual Filter has 3% frequency accuracy and offers exceptional performance and versatility at a modest cost.

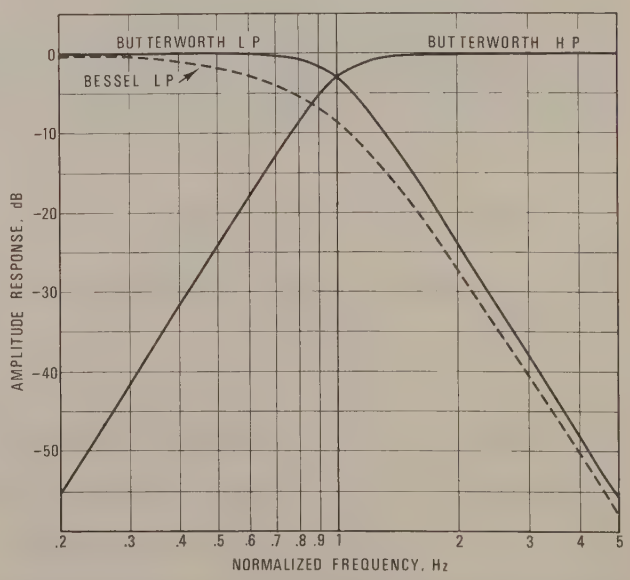
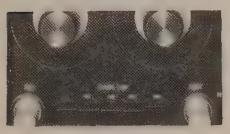


Figure 2 Normalized Frequency Response of 4 Pole Filters

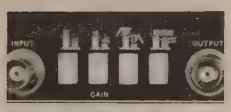
FILTERS AND AMPLIFIERS

Most signal measuring systems that require filters also require amplification of the signal. ITHACO filters make it convenient to add gain in three ways:



4210 w/Gain Option

- In the 4210 Series Filters, an optional 0 to 40 dB internal post amplifier, with gain selectable in 10 dB steps by front panel control, is available. Two such filters may be cascaded to provide up to 80 dB gain and twice the attenuation slope of a single filter.

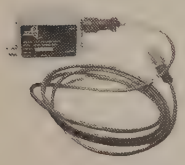


4302 Selectable Gain

- The 4302 Dual Filter has built-in selectable gain of 1 and 10 in each filter section, for total gain of 100 when connected in series.

Model 455

- Compatible ITHACO amplifiers with selectable gain of up to 90 dB are available for use with rack mount filter models.



Remote Preamp w/connector

- All the 4110 and 4210 Series Filters have a rear mounted XLR connector (standard in some, optional in others) that provides power to and receives the signal from any ITHACO low noise preamplifier. Some of these preamps, with fixed gains from 20 to 60 dB are described on page 14.

GAIN DISTRIBUTION

Generally speaking, it is desirable to place the filter in the amplification chain as close to the signal source as the self-noise of the filter will permit. This arrangement maximizes the allowable dynamic range of unwanted signals that the system will accomodate. If the noise of the signal source is larger than the self-noise of the filter, *in the passband of interest*, then no preamplifier is required. Otherwise, a fixed gain preamplifier, with its input characteristics optimized for the particular signal source, should be used just ahead of the filter. The remainder of the gain should be placed either after the filter or distributed within the filter poles. The gain options described above provide near-optimum gain distribution.

For a discussion of filter and preamplifier noise, see page 14.

BUTTERWORTH AND BESSEL

In the majority of applications, the user wants flat, attenuation-free response in the passband, and maximum attenuation outside it. This criterion is best met by the Butterworth (maximally flat) filter. (see Figure 2)

In some cases, pulse work in particular, it is desirable to preserve waveform (linear phase response) and to have constant delay within the passband. The Bessel filter is an effective solution to this requirement. Flatness in the passband and attenuation outside the passband are sacrificed for optimum phase characteristics and good transient response. Expedient solutions used in competitive filters, such as cascaded RC and "low Q" filters are recognized to be inferior to the Bessel filter. (see Figures 3 and 4).

The frequency and time domain data shown represent the theoretical performance of the Butterworth and Bessel 4 pole filters. These curves accurately depict the performance of the ITHACO filters described in this brochure.

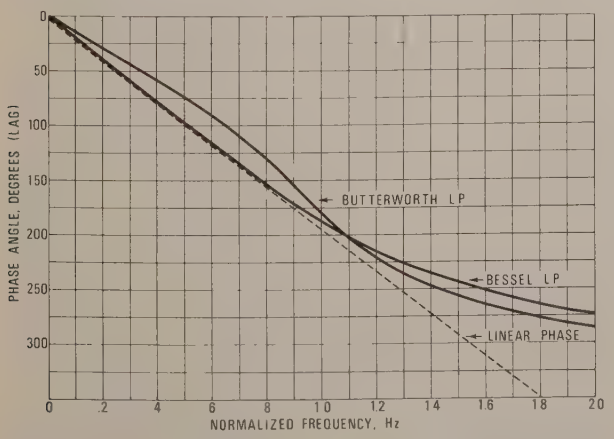


Figure 3 Normalized Phase Response of 4 pole L.P. Filters

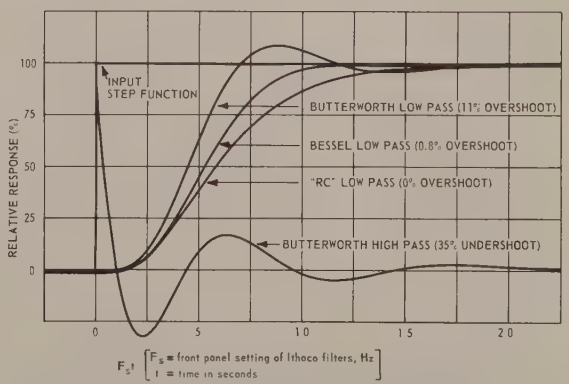
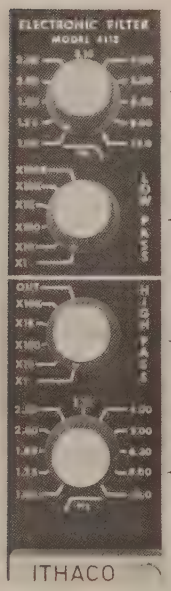


Figure 4 Step Function Response of 4 pole Filters

4110 series high-pass, low-pass, bandpass filters



Set Low-Pass Frequency in 1/10 decade steps

Low-Pass Frequency Multiplier

High-Pass Frequency Multiplier

Set High-Pass Frequency in 1/10 decade steps

The ITHACO 4110 Series Filters are designed for multichannel applications.

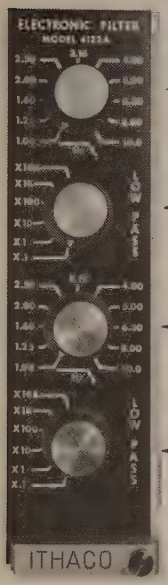
This series consists of precision, active filters with frequency selectable by front panel controls in 1/10 decade steps. This provides 10 equally spaced settings per decade on a logarithmic scale, and permits bandpass operation in octave, decade, and other convenient bandwidths. Phase and amplitude tracking between filters with the same setting will be within ± 4° and ± .2 dB respectively.

The 4110 Series is compatible with ITHACO 450, 460 and 470 Series Amplifiers.

specifications

FILTER MODES		High-Pass, Low-Pass, Bandpass. Butterworth only
FREQUENCY SETTINGS		1.0, 1.25, 1.6, 2.0, 2.5, 3.15, 4.0, 5.0, 6.3, 8.0, 10.0
FREQUENCY RANGES *Highest decade of low-pass filter section operates with reduced phase and cutoff frequency accuracy. (± 5% accuracy typical)	MODEL	HIGH-PASS / LOW-PASS
	4111	.01 Hz – 1 kHz / .01 Hz – 10 kHz *
	4112	.1 Hz – 10 kHz / .1 Hz – 100 kHz *
	4113	1 Hz – 100 kHz / 1 Hz – 1 MHz *
CUTOFF FREQUENCY ACCURACY		±1%
FREQUENCY STABILITY		Less than 200 ppm/°C/pole
PHASE ACCURACY		±2°
ATTENUATION SLOPE		24 dB/octave, 80 dB/decade (4 pole)
MAXIMUM ATTENUATION		90 dB (70 dB highest decade in LP)
INSERTION LOSS		0 dB ±.1 dB
DISTORTION		Less than 0.1% at 5 volts rms into 5K Ω load at 1 kHz
HUM AND NOISE		Less than 70μ volts rms with 100 kHz detector bandwidth
FILTER DRIFT		100μV/°C + 250μV/day referred to the output (4111) 50μV/°C + 250μV/day referred to the output (4112, 4113)
INPUT (Single Ended)	Connector	Rear Panel: BNC
	Max Linear Input	±7V pk (diode protected) to 100 kHz decreasing to ±1V @ 1 MHz
	Coupling	dc coupled in LP, ac coupled in HP and BP (ac + dc < 200V)
	Impedance	22MΩ ±10%//60 pF max
OUTPUT (Single Ended)	Connector	Rear Panel: BNC
	Maximum Output	±7 volts peak; ±5 Ma peak (short circuit protected)
	Impedance	50Ω ±10% dc coupled
	Offset	Internally adjustable to zero with HP in "out" position
POWER		External ±15V @ 100 Ma
ENVIRONMENT		–20°C to +55°C operating; –55°C to +85°C storage; R.H. 95%
DIMENSIONS AND WEIGHT		6.75" h x 2" w x 10.5" d; 3 lbs

4120A series dual low-pass filters



Set Low–Pass Frequency in 1/10 decade steps

Low–Pass Frequency Multiplier

Set Low–Pass Frequency in 1/10 decade steps

Low–Pass Frequency Multiplier

ITHACO 4120A Series Filters are dual channel, low–pass filters designed for high density, multichannel applications.

Each plug–in filter module consists of 2 independent signal channels, each of which exhibits a 4 pole, maximally flat (Butterworth) low–pass filter characteristic, settable in 1/3 octave (1/10 decade) steps. The use of precision components in these filters permits close amplitude and phase tracking between units set at the same frequency settings. In addition, large signal handling capability and low self–noise provide a wide dynamic operating range.

The compact modular construction of the 4120A Series permit up to 14 individual signal channels in 19" x 7" of rack space.

specifications (per channel)

FILTER MODES		Low–Pass Butterworth only
FREQUENCY SETTINGS		1.0, 1.25, 1.6, 2.0, 2.5, 3.15, 4.0, 5.0, 6.3, 8.0, 10.0
FREQUENCY RANGES Butterworth *Highest decade of low–pass filter section operates with reduced performance. (±5% accuracy typical)		MODEL: 4122A — LOW–PASS: .1 Hz – 100 kHz * MODEL: 4123A — LOW–PASS: 1 Hz – 1 MHz *
CUTOFF FREQUENCY ACCURACY		±1%
FREQUENCY STABILITY		Less than 200ppm/°C/pole
PHASE ACCURACY		±2°
ATTENUATION SLOPE		24 dB/octave, 80 dB decade (4 pole)
MAXIMUM ATTENUATION		90 dB (highest decade)
INSERTION LOSS		0 dB ±.1 dB
DISTORTION		Less than 0.1% at 5 volts rms into 5KΩ load at 1 kHz
HUM AND NOISE		Less than 70μ volts rms with 100 kHz detector bandwidth
FILTER DRIFT		50μV/°C + 250μV/day referred to the output
INPUT (Single Ended)	Connector	Rear Panel: BNC
	Max Linear Input	±7V (diode protected) to 100 kHz decreasing to ±1V @ 1 MHz
	Coupling	dc coupled
	Impedance	22MΩ ±10%//60 pF max
OUTPUT (Single Ended)	Connector	Rear Panel: BNC
	Maximum Output	±7 volts peak, ±5 Ma peak (short circuit protected)
	Impedance	50Ω, dc coupled
	Offset	Internally adjustable to zero
POWER		External ±15V @ 120 Ma (per plug–in)
ENVIRONMENT		–20°C to +55°C operating; –55°C to +85°C storage; R.H. to 95%
DIMENSIONS AND WEIGHT		6.75" h x 2" w x 10.5" d; 3 lbs. (per plug–in)

accessories for 4110 and 4120A series

power supplies

MODEL	P11	P12	P37	P33
VOLTAGE	±15V	±15V, +28V	±15V	±15V, +28V
CURRENT	1 Amp	1 Amp (±15V) 200 ma (+28V)	500 ma	500 ma (±15V) 100 ma (+28V)
LINE REGULATION	.05%	.05%	.05%	.05%
LOAD REGULATION	.01%	.01%	.01%	.01%
ACCURACY	Adjustable	Adjustable	Adjustable	Adjustable
STABILITY	±.1%/day	±.1%/day	±.1%/day	±.1%/day
RIPPLE AND NOISE	45μV rms	45μV rms	45μV rms	45μV rms
CAL OSCILLATOR	No	No	Yes	Yes
MOUNTING CASE	S11, S21	S11, S21	S30	S30
LINE FREQUENCY	47–440 Hz	47–440 Hz	47–440 Hz	47–440 Hz
WEIGHT	9 lbs	9 lbs	1 lb	1 lb
SIZE	6.75" h x 2.75" w x 12.25" d		6.75" h x .72" w x 10" d	
USE WITH	4100 Series	4110 Series w/Option 03	4100 Series	4110 Series w/Option 03

power supply options

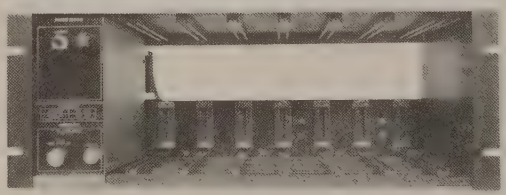
STANDARD – 105V–130V OPTION 01 – 90V–110V OPTION 02 – 180V–220V OPTION 03 – 210V–260V

power supply features

- Short Circuit Protected
- Battery power input terminals on rear connector of mounting case

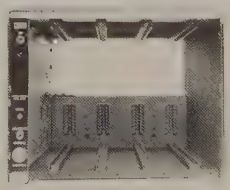
mounting cases

MODEL S11 – 7 CHANNEL MOUNTING CASE



DIMENSIONS: 7" High, 19" Wide, 14" Deep
WEIGHT: 25 lbs including power supply

MODEL S30 – 4 CHANNEL PORTABLE CASE



DIMENSIONS: 7.20" High, 9.12" Wide, 14.35" Deep
WEIGHT: 12 lbs including power supply

remote preamplifier options for 4110 series filters

OPTION 03 Remote Preamplifier +28 Volt Power
Add 5 pin XLR connector to rear panel to supply +28 volts and signal connections to remote preamplifier.

OPTION 09 Remote Preamplifier ±15 Volt Power
Add 5 pin XLR connector to rear panel to supply ±15 volts and signal connections to remote preamplifier.

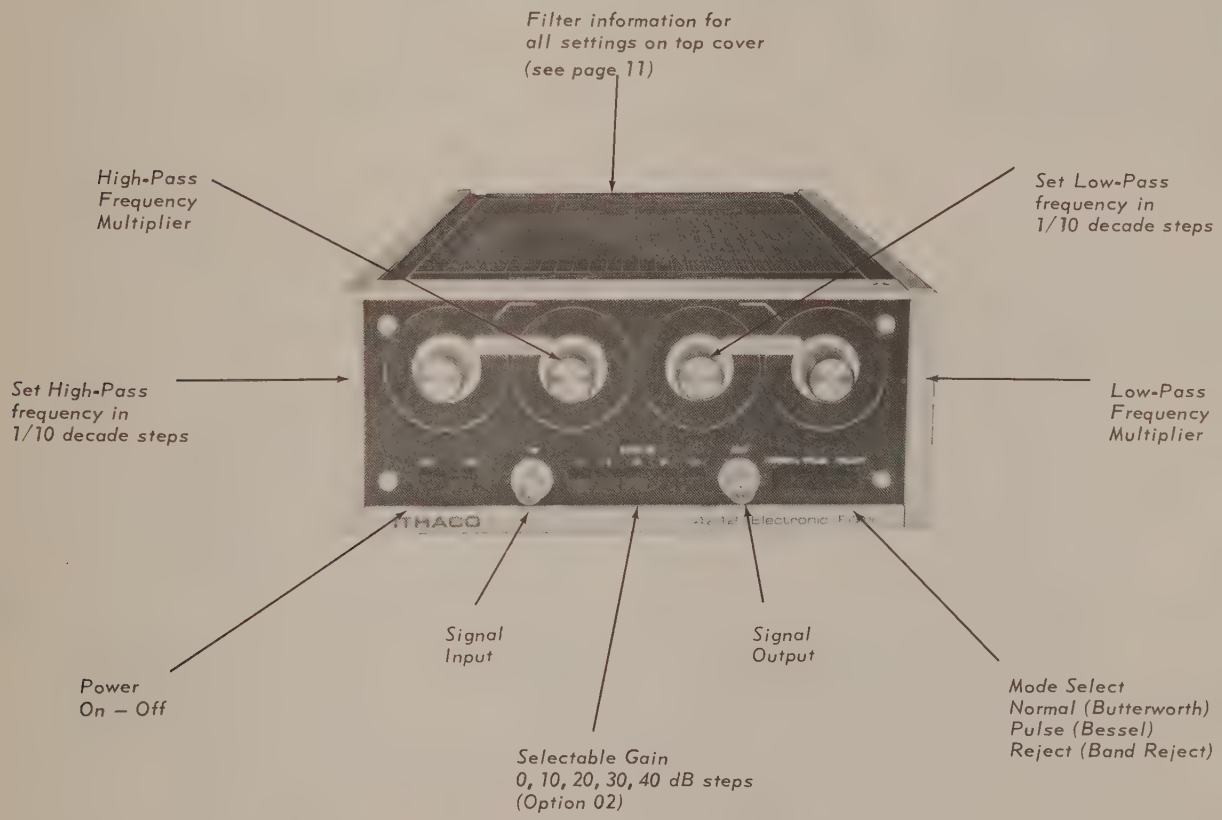
other accessories

X1 Extender Module w/6 ft Cable Y1 Blank Front Panel Z1 Blank Plug–In Chassis

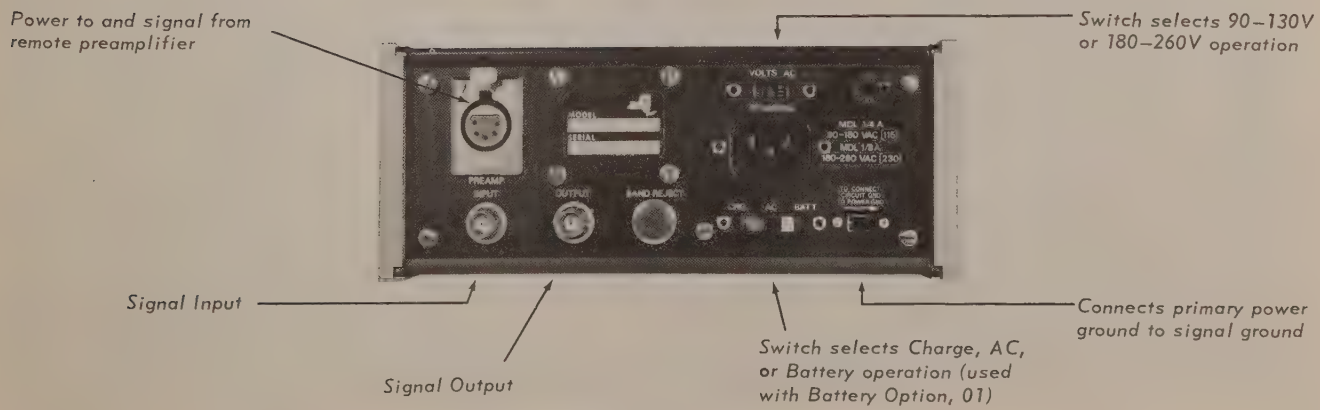
4210 series laboratory filters 1/10 decade steps

The ITHACO 4210 Series Filters consist of cascaded 24 dB/octave high and low-pass sections. Independent control of the high and low-pass cutoff frequencies permits the filter to be used as a dc coupled low-pass filter, a band-limited high-pass filter, a bandpass filter, or a band reject filter. The internationally accepted 1/10 decade frequency settings provide 10 equally spaced settings per decade on a logarithmic scale.

This permits operation in octave, decade, and other convenient bandpass settings. *The filter characteristics are printed on top of the instrument for all filter settings, including those in which the high and low-pass settings are so close to each other that the attenuation and effective cutoff frequencies are affected. These characteristics include –3 dB frequencies, center frequency, –3 dB bandwidth, noise bandwidth, and insertion loss.*


Filter information for all settings on top cover (see page 11)
High-Pass Frequency Multiplier
Set Low-Pass frequency in 1/10 decade steps
Set High-Pass frequency in 1/10 decade steps
Low-Pass Frequency Multiplier
Power On – Off
Signal Input
Signal Output
Mode Select Normal (Butterworth) Pulse (Bessel) Reject (Band Reject)
Selectable Gain 0, 10, 20, 30, 40 dB steps (Option 02)

REAR PANEL


Power to and signal from remote preamplifier
Switch selects 90–130V or 180–260V operation
Signal Input
Signal Output
Switch selects Charge, AC, or Battery operation (used with Battery Option, 01)
Connects primary power ground to signal ground

4210 series specifications

FILTER MODES			High-Pass, Low-Pass, Bandpass, Band Reject Butterworth (normal) and Bessel (pulse)
FREQUENCY SETTINGS			1.0, 1.25, 1.6, 2.0, 2.5, 3.15, 4.0, 5.0, 6.3, 8.0, 10.0
FREQUENCY RANGES *Highest decade of low-pass filter section operates with reduced phase and cutoff frequency accuracy. (±5% accuracy typical)			MODEL: 4211 / HIGH-PASS: .01 Hz – 1 kHz / LOW-PASS: .01 Hz – 10 kHz * 4212 / .1 Hz – 10 kHz / .1 Hz – 100 kHz * 4213 / 1 Hz – 100 kHz / 1 Hz – 1 MHz *
BROADBAND FREQUENCY RANGE			dc to 1 MHz
CUTOFF FREQUENCY ACCURACY			±1% (Butterworth –3 dB, Bessel –8.6 dB)
FREQUENCY STABILITY			200 ppm/°C
PHASE ACCURACY			±2°
ATTENUATION SLOPE			24 dB/octave; 80 dB/decade
MAXIMUM ATTENUATION			90 dB (70 dB highest decade in LP)
INSERTION LOSS			0 dB ±.1 dB (In the bandpass mode, the insertion loss depends on the separation of the low-pass and high-pass cutoff frequencies. If both cutoff frequencies are identical, the insertion loss will be 6 dB. The 4210 Series has the insertion loss at all filter settings printed on top of the instrument.)
DISTORTION			.1%, 5V rms @1 kHz with 5KΩ load
HUM AND NOISE			70μV rms (100 kHz detector bandwidth)
FILTER DRIFT			50μV/°C + 250μV/day referred to the output, 0 dB gain
INPUT (Single Ended)	Connectors		Front and Rear Panels: BNC, Rear Panel: 5 pin XLR
	Max Linear Input (diode protected)	Low-Pass Mode	ac plus dc should not exceed ±7V peak
		High-Pass Mode	ac should not exceed ±7V pk; ac plus dc should not exceed ±200V pk (7V pk to 100 kHz, decreasing to ±1V @ 1 MHz)
	Coupling		dc coupled in LP, ac coupled in HP and BP
	Impedance		22MΩ ±10%//100 pF max.
OUTPUT (Single Ended)	Connector		Front and Rear Panels: BNC
	Maximum Output		±7 volts peak and 5 Ma peak (short circuit protected)
	Impedance		50Ω, dc coupled
POWER			Internal well regulated, isolated power supply with a rear panel switch to disconnect the filter circuit ground from the power ground for floating operation. 90–130 or 180–260 volts (switch selected), single-phase 47–440 Hz, 5 watts
ENVIRONMENT			0°C to +55°C operating; –55°C to +85°C storage; R.H. 95%
DIMENSIONS AND WEIGHT			3.50'' h x 8.50'' w x 13'' d; 8 lbs plus 2 lbs for batteries

options and accessories

OPTIONS	Option 01 – Battery Option	Internal NiCd batteries operate for 4 hours w/o recharging. Recharges on 90–130 or 180–260 volts (switch selected), single-phase, 47–440 Hz, 5 watts. Fully charged in 16 hrs. Filter does not operate in charge mode.
	Option 02 – Amplifier Option	Internal 0/10/20/30/40 dB Gain, Gain Accuracy ±.1 dB
ACCESSORIES	Remote Preamplifiers	See page 14
	Model RM–1	Rack Mounting Kit for Two Filters
	Model RM–2	Rack Mounting Kit for Single Filter
	Model 4200V1	Cable Assembly for use with Remote Preamplifiers

THE FOLLOWING INFORMATION IS PRINTED ON TOP OF THE 4210 SERIES FILTERS:

HIGH-PASS FILTER (LOW-FREQUENCY ROLLOFF)

NORMAL (BUTTERWORTH): −3 dB AND +180° AT THE HIGH-PASS FREQUENCY SETTING
PULSE (BUTTERWORTH). −3 dB AND +180° AT THE HIGH-PASS FREQUENCY SETTING

LOW-PASS FILTER (HIGH-FREQUENCY ROLLOFF)

NORMAL (BUTTERWORTH) −3 dB and −180° AT THE LOW-PASS FREQUENCY SETTING
PULSE (BESSEL): −8.6 dB and −187° AT THE LOW-PASS FREQUENCY SETTING
DC COUPLED. SET HIGH-PASS MULTIPLIER TO OUT

BAND-PASS FILTER (NORMAL MODE ONLY)

WHEN THE LOW-PASS FILTER SETTING, F_{LP} (HIGH FREQUENCY ROLLOFF) DIVIDED BY THE HIGH-PASS FILTER SETTING, F_{HP} (LOW-FREQUENCY ROLLOFF) IS LESS THAN 4, THE CHART BELOW MUST BE CONSULTED FOR BAND-PASS FILTER CHARACTERISTICS. (FOR USERS CONVENIENCE, THE FILTER CHARACTERISTICS HAVE BEEN TABULATED FOR F_{LP} F_{HP} ≤ 10)

DIRECTIONS:

$$\frac{F_{LP}}{F_{HP}} > 4$$

UPPER −3 dB FREQUENCY	= LOW-PASS CUTOFF FREQUENCY	−3 dB BANDWIDTH	= $F_{LP} - F_{HP}$
CENTER FREQUENCY	= $\sqrt{F_{HP} \cdot F_{LP}}$	NOISE BANDWIDTH	= 1.025 ($F_{LP} - F_{HP}$)
LOWER 3 dB FREQUENCY	= HIGH-PASS CUTOFF FREQUENCY	FILTER GAIN	= 0.0 dB

$$\frac{F_{LP}}{F_{HP}} \leqslant 4$$

1. DIVIDE THE CUTOFF FREQUENCY SETTINGS BY HIGH-PASS MULTIPLIER TO OBTAIN NORMALIZED SETTINGS.
2. OBTAIN THE FILTER GAIN AND NORMALIZED FREQUENCIES FROM TABLE USING NORMALIZED SETTINGS.
3. MULTIPLY NORMALIZED FREQUENCIES OBTAINED FROM TABLE BY HIGH-PASS MULTIPLIER.

EXAMPLE

HIGH-PASS CUTOFF FREQUENCY, Hz = 6.30×10^3 (Divide by High-Pass Multiplier) → NORMALIZED HIGH-PASS SETTING 6.30

LOW-PASS CUTOFF FREQUENCY, Hz = 1.00×10^4 → NORMALIZED LOW-PASS SETTING = 10.0

	NORMALIZED (From Table)		ACTUAL
UPPER −3 dB FREQUENCY, Hz	10.70	(Multiply by High-Pass Multiplier) →	1.07×10^4
CENTER FREQUENCY, Hz	7.937		7.937×10^3
LOWER −3 dB FREQUENCY, Hz	5.932		5.932×10^3
−3 dB BANDWIDTH, Hz	4.768		4.768×10^3
NOISE BANDWIDTH, Hz	5.339		5.339×10^3
FILTER GAIN, dB	−1.23	(Gain not normalized) →	−1.23

NORMALIZED HIGH-PASS SETTING		NORMALIZED LOW-PASS SETTING																		
		1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	25.0	31.5	40.0	50.0	63.0	80.0	100
1.00	UPPER −3 dB FREQ., Hz	1.245	1.418	1.699	2.057	2.530	3.165	4.000	5.000	6.300	8.000	10.00	12.50	16.00	20.00	25.00	31.50	40.00	50.00	63.00	80.00	100.0
	CENTER FREQ., Hz	1.000	1.118	1.265	1.414	1.581	1.774	2.000	2.236	2.510	2.828	3.162	3.536	4.000	4.472	5.000	5.612	6.325	7.071	7.937	8.944	10.00
	LOWER −3 dB FREQ., Hz	0.803	0.881	0.942	0.972	0.988	0.995	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	−3 dB BANDWIDTH, Hz	0.442	0.537	0.757	1.085	1.542	2.170	3.002	4.000	5.300	7.000	9.000	11.50	15.00	19.00	24.00	30.50	39.00	49.00	62.00	79.00	99.00
	NOISE BANDWIDTH, Hz	.513	.612	.848	1.163	1.620	2.252	3.105	4.097	5.414	7.178	9.226	11.79	15.38	19.48	24.60	31.26	39.99	50.23	63.53	81.00	101.5
	FILTER GAIN, dB	6.02	2.98	1.27	−0.53	0.22	−0.09	−0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.25	UPPER −3 dB FREQ., Hz		1.556	1.777	2.124	2.571	3.163	3.956	5.000	6.300	8.000	10.00	12.50	16.00	20.00	25.00	31.50	40.00	50.00	63.00	80.00	100.0
	CENTER FREQ., Hz		1.250	1.414	1.551	1.760	1.984	2.236	2.500	2.806	3.162	3.536	3.953	4.472	5.000	5.590	6.275	7.071	7.906	8.874	10.00	11.14
	LOWER −3 dB FREQ., Hz		1.004	1.101	1.177	1.215	1.235	1.245	1.247	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250
	−3 dB BANDWIDTH, Hz		0.552	0.672	0.947	1.356	1.928	2.711	3.753	5.050	6.750	8.750	11.25	14.75	18.75	23.75	30.25	38.75	48.75	61.75	78.75	98.75
	NOISE BANDWIDTH, Hz		.641	.766	1.059	1.454	2.025	2.815	3.877	5.176	6.919	8.974	11.53	15.12	19.21	24.35	31.01	39.72	49.95	63.31	80.72	101.3
	FILTER GAIN, dB		6.02	2.98	1.23	−0.53	−0.22	0.09	−0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.60	UPPER −3 dB FREQ., Hz			1.992	2.269	2.718	3.291	4.048	5.064	6.400	8.000	10.00	12.50	16.00	20.00	25.00	31.50	40.00	50.00	63.00	80.00	100.0
	CENTER FREQ., Hz			1.600	1.789	2.000	2.245	2.530	2.828	3.175	3.578	4.000	4.472	5.060	5.657	6.325	7.099	8.000	8.944	10.04	11.31	12.65
	LOWER −3 dB FREQ., Hz			1.284	1.410	1.506	1.556	1.581	1.592	1.597	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600
	−3 dB BANDWIDTH, Hz			0.708	0.859	1.212	1.735	2.467	3.472	4.803	6.400	8.400	10.90	14.40	18.40	23.40	29.90	38.40	48.40	61.40	78.40	98.40
	NOISE BANDWIDTH, Hz			.821	.979	1.357	1.860	2.591	3.602	4.966	6.561	8.610	11.17	14.76	18.86	23.99	30.65	39.36	49.60	62.95	80.35	100.8
	FILTER GAIN, dB			6.02	2.98	1.23	−0.53	−0.22	−0.09	−0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	UPPER −3 dB FREQ., Hz				2.480	2.836	3.398	4.113	5.060	6.330	8.000	10.00	12.50	16.00	20.00	25.00	31.50	40.00	50.00	63.00	80.00	100.0
	CENTER FREQ., Hz				2.000	2.236	2.510	2.828	3.162	3.550	4.000	4.472	5.000	5.657	6.325	7.071	7.937	8.944	10.00	11.22	12.65	14.14
	LOWER −3 dB FREQ., Hz				1.606	1.762	1.882	1.945	1.976	1.990	1.996	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
	−3 dB BANDWIDTH, Hz				0.874	1.074	1.516	2.168	3.084	4.340	6.004	8.000	10.50	14.00	18.00	23.00	29.50	38.00	48.00	61.00	78.00	98.00
	NOISE BANDWIDTH, Hz				1.026	1.225	1.696	2.325	3.240	4.503	6.209	8.204	10.76	14.35	18.45	23.58	30.23	38.95	49.20	62.52	79.98	100.5
	FILTER GAIN, dB				−6.02	2.98	−1.23	−0.53	0.22	0.09	−0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.50	UPPER −3 dB FREQ., Hz					3.113	3.545	4.247	5.142	6.325	7.913	10.00	12.50	16.00	20.00	25.00	31.50	40.00	50.00	63.00	80.00	100.0
	CENTER FREQ., Hz					2.500	2.806	3.162	3.536	3.969	4.472	5.000	5.590	6.325	7.071	7.906	8.874	10.00	11.18	12.55	14.11	15.81
	LOWER −3 dB FREQ., Hz					2.008	2.203	2.354	2.431	2.470	2.487	2.495	2.500	2.500	2.500	2.500	2.500	2.500	2.500	2.500	2.500	2.500
	−3 dB BANDWIDTH, Hz					1.105	1.342	1.892	2.711	3.855	5.426	7.505	10.00	13.50	17.50	22.50	29.00	37.50	47.50	60.50	77.50	97.50
	NOISE BANDWIDTH, Hz					1.282	1.531	2.246	2.907	4.050	5.630	7.754	10.24	13.84	17.95	23.07	29.72	38.46	48.70	62.02	79.43	99.88
	FILTER GAIN, dB					−6.02	2.98	−1.23	0.53	0.22	0.09	−0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.15	UPPER −3 dB FREQ., Hz						3.921	4.467	5.352	6.478	7.970	9.970	12.60	16.00	20.00	25.00	31.50	40.00	50.00	63.00	80.00	100.0
	CENTER FREQ., Hz						3.150	3.550	3.969	4.455	5.020	5.612	6.275	7.099	7.937	8.874	9.961	11.22	12.55	14.09	15.87	17.75
	LOWER −3 dB FREQ., Hz						2.523	2.775	2.966	3.063	3.144	3.146	3.148	3.150	3.150	3.150	3.150	3.150	3.150	3.150	3.150	3.150
	−3 dB BANDWIDTH, Hz						1.398	1.692	2.356	3.415	4.826	6.824	9.452	12.85	16.85	21.85	28.35	36.85	46.85	59.85	76.85	96.85
	NOISE BANDWIDTH, Hz						1.616	1.930	2.670	3.664	5.105	7.096	9.772	13.17	17.27	22.40	29.07	37.76	48.03	61.38	78.80	99.31
	FILTER GAIN, dB						6.02	2.98	1.23	−0.53	0.22	−0.09	−0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00	UPPER −3 dB FREQ., Hz							4.980	5.672	6.796	8.226	10.12	12.66	16.00	20.00	25.00	31.50	40.00	50.00	63.00	80.00	100.0
	CENTER FREQ., Hz							4.000	4.472	5.020	5.657	6.325	7.071	8.000	8.944	10.00	11.22	12.65	14.14	15.87	17.89	20.00
	LOWER −3 dB FREQ., Hz							3.212	3.524	3.766	3.890	3.952	3.980	3.992	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
	−3 dB BANDWIDTH, Hz							1.768	2.148	3.030	4.736	6.168	8.680	12.01	16.00	21.00	27.50	36.00	46.00	59.00	76.00	96.00
	NOISE BANDWIDTH, Hz							2.051	2.449	3.392	4.651	6.479	9.005	12.42	16.41	21.53	28.19	36.90	47.15	60.46	77.89	98.40
	FILTER GAIN, dB							−6.02	2.98	1.23	−0.53	0.22	0.09	−0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.00	UPPER −3 dB FREQ., Hz								6.225	7.090	8.495	10.28	12.65	16.08	20.00	25.00	31.50	40.00	50.00	63.00	80.00	100.0
	CENTER FREQ., Hz								5.000	5.612	6.325	7.071	7.906	8.944	10.00	11.18	12.55	14.14	15.81	17.75	20.00	22.36
	LOWER −3 dB FREQ., Hz								4.015	4.405	4.708	4.862	4.940	4.975	4.990	5.000	5.000	5.000	5.000	5.000	5.000	5.000
	−3 dB BANDWIDTH, Hz								2.210	2.685	3.787	5.418	7.710	11.11	15.01	20.00	26.50	35.00	45.00	58.00	75.00	95.00
	NOISE BANDWIDTH, Hz								2.564	3.062	4.241	5.814	8.100	11.26	15.51	20.49	27.07	35.89	46.12	59.43	76.91	97.39
	FILTER GAIN, dB								−6.02	2.98	−1.23	−0.53	−0.22	−0.09	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6.30	UPPER −3 dB FREQ., Hz									7.843	8.933	10.70	12.96	15.94	19.94	25.20	31.50	40.00	50.00	63.00	80.00	100.0
	CENTER FREQ., Hz									6.300	7.099	7.937	8.874	10.04	11.22	12.55	14.09	15.87	17.75	19.92	22.45	25.16
	LOWER −3 dB FREQ., Hz									5.059	5.550	5.932	6.126	6.224	6.268	6.287	6.300	6.300	6.300	6.300	6.300	6.300
	−3 dB BANDWIDTH, Hz									2.784	3.383	4.768	6.834	9.716	13.67	18.91	25.20	33.70	43.70	56.70	73.70	91.70
	NOISE BANDWIDTH, Hz									3.232	3.898	5.339	7.328	10.21	14.19	19.54	25.82	34.51	44.79	58.14	75.51	96.05
	FILTER GAIN, dB									−6.02	2.98	−1.23	−0.53	−0.22	0.09	−0.03	0.00	0.00	0.00	0.00	0.00	0.00
8.00	UPPER −3 dB FREQ., Hz										9.960	11.34	13.59	16.45	20.24	25.32	32.00	40.00	50.00	63.00	80.00	100.0
	CENTER FREQ., Hz										8.000	8.944	10.00	11.31	12.65	14.14	15.87	17.89	20.00	22.45	25.10	28.28
	LOWER −3 dB FREQ., Hz										6.424	7.048	7.533	7.779	7.904	7.960	7.984	8.000	8.000	8.000	8.000	8.000
	−3 dB BANDW DTH, Hz										3.536	4.292	6.057	8.671	12.34	17.36	24.02	32.00	42.00	55.00	72.00	92.00
	NOISE BANDWIDTH, Hz										4.102	4.898	6.784	9.300	12.96	18.01	24.83	32.81	43.05	56.38	73.79	94.30
	FILTER GAIN, dB										6.02	2.98	1.23	−0.53	0.22	0.09	0.03	0.00	0.00	0.00	0.00	0.00
10.0	UPPER −3 dB FREQ., Hz											12.45	14.18	16.99	20.57	25.30	31.65	40.00	50.00	63.00	80.00	100.0
	CENTER FREQ., Hz											10.00	11.18	12.65	14.14	15.81	17.75	20.00	22.36	25.10	28.28	31.62
	LOWER −3 dB FREQ., Hz											8.030	8.810	9.416	9.724	9.880	9.950	9.980	10.00	10.00	10.00	10.00
	−3 dB BANDWIDTH, Hz											4.420	5.370	7.574	10.85	15.42	21.70	30.02	40.00	53.00	70.00	90.00
	NOISE BANDWIDTH, Hz											5.129	6.124	8.482	11.63	16.20	27.05	31.05	41.02	54.14	71.78	92.26
	FILTER GAIN, dB											6.02	2.98	1.23	−0.53	−0.22	0.09	0.03	0.00	0.00	0.00	0.00

BAND-REJECT FILTER

1. SET THE HIGH-PASS FILTER CUTOFF ABOVE THE LOW-PASS FILTER CUTOFF.
2. SET THE AMPLIFIER GAIN TO 0 dB.

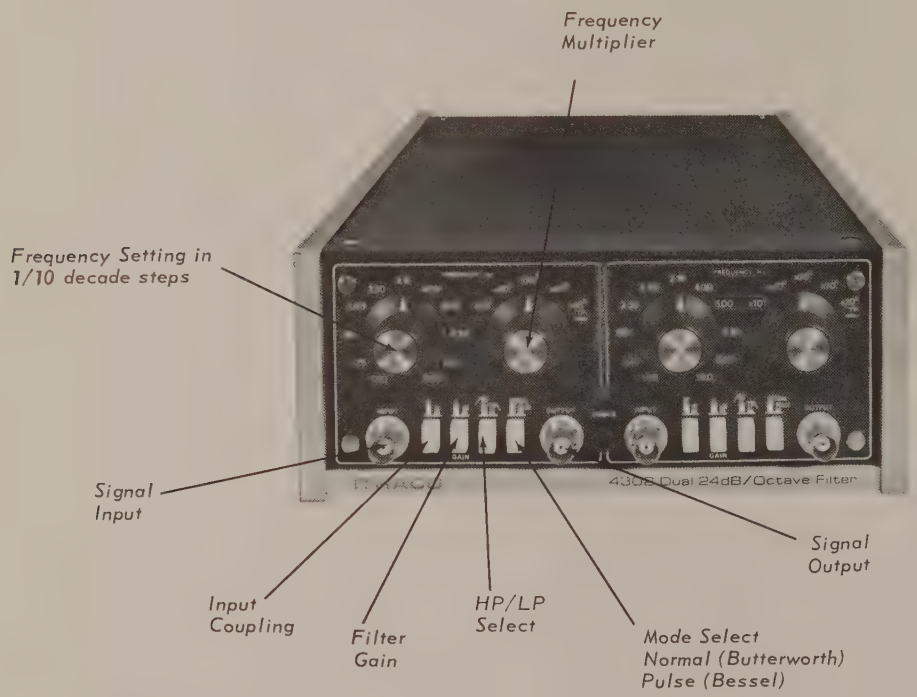
NOTCH FREQUENCY = $\sqrt{F_{HP} \cdot F_{LP}}$
FILTER GAIN = −6 dB

UPPER −3 dB FREQUENCY = F_{HP}
LOWER −3 dB FREQUENCY = F_{LP}

4302 dual 24 dB/octave filter 1/10 decade steps

The Model 4302 Dual Filter is a high performance, low priced, general purpose filter for use in the laboratory as well as in multiple channel data acquisition applications. Covering the 10 Hz to 1 MHz frequency range, the 4302 consists of a pair of identical 24 dB/octave filter channels, each of which can be used as a high pass or a low pass filter with selectable gain of 1 or 10. The two filter channels can be connected in series to produce a single 24 dB/octave bandpass, a 48 dB/octave high pass, or a 48 dB/octave low pass filter, with selectable gain of 1, 10, or 100. Butterworth (Normal) or Bessel (Pulse) modes can be selected by front panel switches. Frequency and pulse response curves are shown below. AC/DC input coupling switches on the front panel make it possible to use one or both channels as AC or DC coupled low pass filters. In the AC mode, large DC offsets can be accommodated, and the filter will have a low frequency cutoff at approximately .07 Hz.

Specifications of the 4302 are uniformly outstanding. Of particular interest are its very low distortion – .005% at 20 volts peak to peak output, 25μvolts self noise, 100 dB outband rejection performance, and 100 dB crosstalk attenuation. Frequency accuracy is ±3% of setting.



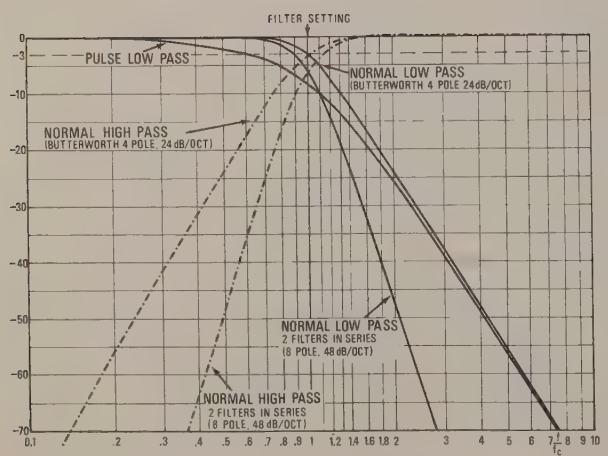


Figure 6 Normalized Response

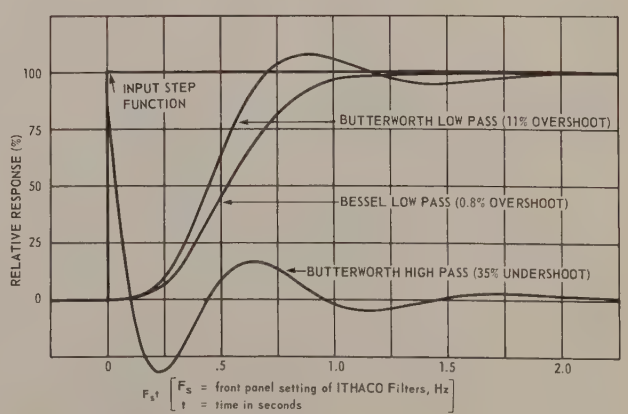


Figure 7 Step Response of 4 Pole Filter

4302 specifications (per channel)

FILTER MODES	Low–Pass (Normal)	4 pole Butterworth LP for maximum flat amplitude response	
	Low–Pass (Pulse)	4 pole LP with maximum flat time delay (approaches Bessel)	
	High–Pass (Normal)	4 pole Butterworth HP (upper –3 dB at approx. 950 kHz (–4 dB typical at 1 MHz)	
FREQUENCY SETTINGS	1.00, 1.25, 1.60, 2.00, 2.50, 3.15, 4.00, 5.00, 6.30, 8.00, 10.0		
FREQUENCY RANGES	MULTIPLIER	FREQUENCY RANGE	
	$\times 10^1$	10 – 100 Hz	HP or LP
	$\times 10^2$	100 – 1 kHz	HP or LP
	$\times 10^3$	1K – 10 kHz	HP or LP
	$\times 10^4$	10K – 100 kHz	HP or LP
	$\times 10^5$	100K – 1 MHz	LP only
CORNER FREQUENCY ACCURACY	±3% (NORMAL: –3.01 dB; PULSE: –8.36 dB) except 100 kHz to 1 MHz Typical frequency response between 100 kHz and 1 MHz will be within ±2 dB of ideal response shown in Figure 6.		
ATTENUATION SLOPE	24 dB/octave; 80 dB/decade each filter. Cascade for 48 dB/octave low–pass or high–pass: For 48 dB/octave low–pass, set filters equal. Cutoff frequency is 10% lower than setting (Figure 6). For 48 dB/octave high–pass, set filters equal. Cutoff frequency is 10% higher than setting (Figure 6).		
MAXIMUM ATTENUATION	Better than 100 dB to 100 kHz. Typically 80 dB at 1 MHz (Measured at ×10 gain, 10 Hz LP)		
VOLTAGE GAIN	Switch selectable 1 or 10; ±3%		
DISTORTION (Typically)	× 1 gain: Less than .03%, 1 kHz ×10 gain: Less than .005%, 1 kHz (20V pp, no load or 10V pp into 600 Ω		
HUM AND NOISE	Less than 75μV rms (100 kHz NBW) × 1 gain Less than 25μV rms (100 kHz NBW) ×10 gain	(both referred to input)	
INPUT	Modes	AC (.07 Hz cutoff), DC; selected by front panel switching	
	Maximum Input Voltages (Diode Protected Input)	DC Mode: 20V pk to pk for linear operation AC Mode: ±200 VDC and 20V pk to pk signal	
	Impedance	22MΩ // 20 pF	
	Connector	BNC on front panel	
OUTPUT	Maximum Output Swing	20V pk to pk, no load; 10V pk to pk into 600 Ω	
	Impedance	600 Ω ±1%, DC coupled	
	Offset	Less than 50 mV typical	
	Connector	BNC on front panel	
POWER	88 – 110 VAC 104 – 130 VAC 192 – 240 VAC 220 – 260 VAC	50 – 400 Hz, 4 Watts voltage range may be selected by reversing card in fuse holder	
FUSE	125 mA, Slow Blow		
ENVIRONMENT	0°C to +55°C Operating; –55°C to +85°C Storage; R.H. 95%		
DIMENSIONS	3.5" high × 8.5" wide × 13" deep		
WEIGHT	6 lbs, 10½ oz.		
ACCESSORIES	Model RM–1 Rack Mounting Kit for Two Filters Model RM–2 Rack Mounting Kit for Single Filter		

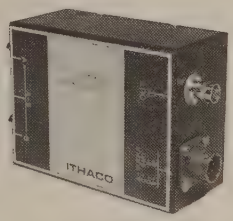
preamplifiers for 4110* and 4210 series filters

REMOTE PREAMPLIFIER SPECIFICATIONS							
MODEL	143L	144L	165		166	167	168
			TRANSFORMER	DIRECT			
INPUT	Single–Ended	Single–Ended	Differential	Single–Ended	Single–Ended	Single–Ended	Differential
INPUT Z	1000M//15pF	1000M//15pF	10KΩ	100M//25pF	40K//25pF	100M//25pF	100M//25pF
BANDWIDTH	.5Hz–200kHz	.5Hz–200kHz	1Hz–5kHz(10Ω)	.1Hz–1MHz	.1Hz–210kHz	.1Hz–1MHz	.02Hz–1MHz
GAIN	10 (20dB)	100 (40dB)	1000 (60dB)	10 (20dB)	100 (40dB)	10 (20dB)	10 (20dB)
OUTPUT VOLTS	±8V	±8V	±10V	±10V	±4V	±10V	±5V
P S VOLTAGE	+28V	+28V	±15V	±15V	−15V	±15V	±15V
NOISE	SEE BELOW						

Model 144L

Model 165

Model 167



Model 168

* TO USE A PREAMPLIFIER WITH A 4110 SERIES FILTER, EITHER OPTION 03 OR 09 IS REQUIRED.

noise

To compute filter or preamplifier noise for any source impedance and any bandwidth:

In Figure 5, Z_s is the complex impedance of the source. e_n and i_n are input stage noise voltage and current respectively. Total noise E_n referred to the input is:

$$E_n = \sqrt{[e_n^2 + (i_n Z_s)^2]}\ BW,$$ where BW is the bandwidth of interest. For broadband computations where e_n and i_n are not constant:

a) Divide bandwidth of interest into small intervals.

b) Compute noise for each such interval using the average values of e_n and i_n for that interval.

c) Make an rms summation of the noise for all intervals to find E_n (See IAN–102)

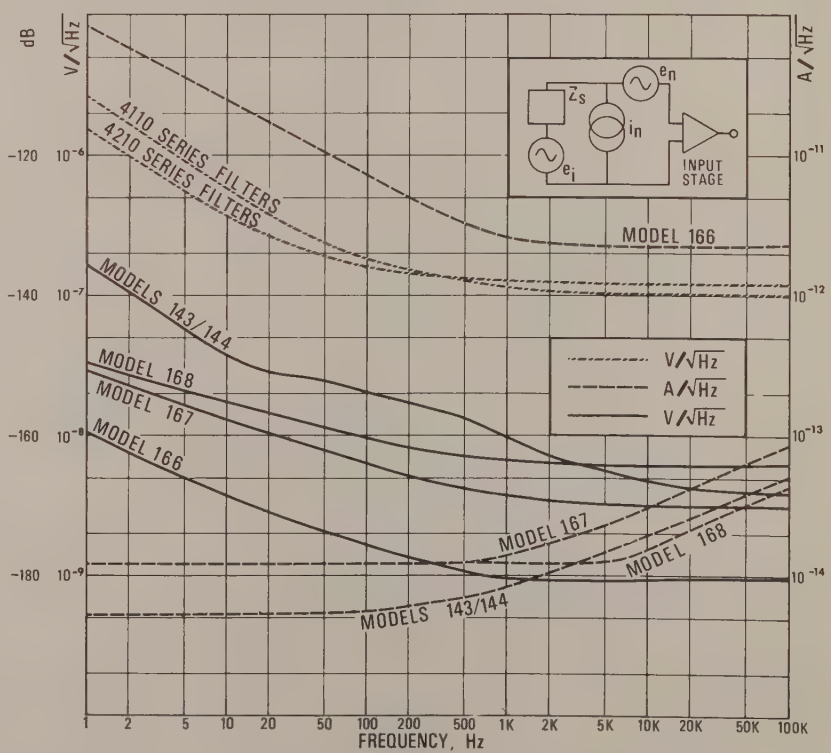


Figure 5 Spectral noise of filters and accessory preamplifiers

ITHACO PRODUCTS INCLUDE:

scientific and engineering

lock–in amplifiers, light beam choppers, ratiometers, low noise preamplifiers, electronic filters

data acquisition

instrumentation amplifiers, seismic amplifiers, auto–ranging amplifiers, computer–controlled amplifiers, charge amplifiers, dynamic strain amplifiers, low noise preamplifiers, multiple channel electronic filters, anti alias filters

agricultural

ultrasonic instruments for live animal evaluation

spacecraft

horizon scanners and attitude control system components

735 WEST CLINTON STREET, BOX 818, ITHACA, NEW YORK 14850 USA

PHONE 607–272–7640 TWX 510–255–9307

IPS 104 6/80

PRINTED IN USA

2.0 INSTALLATION

2.1 INSPECTION

2.1.1 GENERAL

Before shipment, this unit was found to be free of electrical and mechanical defects. As soon as the instrument is unpacked, inspect for any damage that may have occurred in transit. Save all packing materials until the inspection is complete. If damaged in any way, a claim should be filed with the carrier and a copy forwarded to ITHACO. ITHACO will then advise you as to the disposition of the equipment and will arrange for repair or replacement without waiting for a settlement of a claim against the carrier.

2.1.2 VISUAL INSPECTION

A visual check should be made to confirm that there are no broken knobs or connectors, and that the case and panel surfaces are free of dents and scratches.

2.1.3 ELECTRICAL INSPECTION

The instrument should be checked against its electrical specifications (see Section 5).

2.2 SYSTEM GROUNDS

A system ground terminal is provided on the rear of each mounting case which permits the power ground to be jumpered to system ground by means of a terminal clip. In those systems which are operated with other portions of the system connected to power ground, it may be advantageous to operate without this jumper.

3.0 OPERATION

3.1 GENERAL

The ITHACO 4110 Series Variable Electronic Filters will operate as either a DC-coupled low-pass filter, a band-limited high-pass filter, or a band-pass filter by suitable selection of operating controls. Operating controls of the 4110 Series Filters and associated equipment are described in Figures 3.1 and 3.2.

3.2 NORMALIZED FILTER CHARACTERISTICS

3.2.1 INTRODUCTION

The frequency response for the high-pass filter section and the low-pass filter can be determined by scaling a normalized filter plot. The Normalized Filter Response for all Filter Ranges is plotted in Figure 3.3, (see Figures 1 and 2 in IAN 101).

3.2.2 NORMALIZED FILTER RESPONSE

Referring to Figure 3.3, the frequency scale has been normalized so that the filter cut-off frequency (FREQUENCY SETTING X FREQUENCY MULTIPLIER on front panel) is indicated by unity on this scale. To determine the frequency response for a particular setting the scale on the graph is multiplied by the filter cut-off frequency. For example, if the filter cut-off frequency is set to 2KHz, then "1" on the normalized frequency scale will indicate 2KHz, "2" on the normalized frequency scale will indicate 4KHz, "5" on the normalized frequency scale will indicate 10KHz, ".5" on the normalized scale will indicate 1KHz, etc. In this manner a single curve can specify the response for all filter settings.

3.3 AC COUPLED INPUT

When operating with the high-pass multiplier switch set to the OUT position, the 4110 Series filters are DC coupled. When operating with the high-pass multiplier switch to a position other than the OUT position, the 4110 Series filters have an AC coupled input stage in addition to the 4 pole Butterworth high-pass filter. This permits the input to operate from signal sources which possess a DC component as high as 200 volts. The ac coupled input consists of a 2μfd capacitor coupled into 22 Megohm resistor so the -3 dB frequency for this network is .004 Hz and should have little effect in most applications. The phase and amplitude response of the AC coupled input is plotted in Figure 3.4.

3.4 OPERATION AS A BAND-PASS FILTER (Low-Pass Filter Setting $\geq$ High-Pass Filter Setting)

The 4110 Series Filters consist of a separate variable high-pass filter and a low-pass filter in cascade. The setting of the high-pass filter determines the low frequency rolloff where as the setting of the high frequency rolloff is determined by the low-pass filter. The high frequency cutoff is determined by the low-pass filter and the low frequency cutoff is determined by the high-pass filter when the two cutoffs are separated by more than one octave. When the high and low cutoff frequency are less than one octave, the filter possesses an insertion loss (loss in gain) and the -3 dB cutoff frequencies differ from the front panel settings. The -3 dB frequencies, center frequency, bandwidth, noise bandwidth, and filter gain are given in the enclosed Application Note IAN-101 "Phase and Amplitude Response of a Variable Electronic Filter".

IAN-101

PHASE AND AMPLITUDE RESPONSE OF A VARIABLE ELECTRONIC FILTER

ITHACO

735 WEST CLINTON STREET ITHACA NEW YORK 14850 PHONE 607-272-7640 TWX 510-255-9307

ABSTRACT

The phase and amplitude response of a 4 pole Butterworth low-pass, 4 pole Butterworth high-pass and 4 pole Bessel low-pass filters are provided. Also, the phase and amplitude response of a band-pass filter formed by cascaded 4 pole Butterworth high and low-pass filters are provided for cut-off separations of 0/10, 1/10, 2/10, 3/10 decade. A simple general method is described for obtaining the phase and amplitude response of cascaded 4 pole Butterworth high and low-pass filters for any filter separation in 1/10 decade steps. The –3 dB frequencies, center frequency, –3 dB bandwidth, noise bandwidth and filter gain are tabulated for ITHACO Variable Electronic Filters such that this information can be obtained for any filter setting.

INTRODUCTION

A Variable Electronic Filter as described in this paper is comprised of independently tuned high-pass and low-pass filter sections with provisions to operate as a low-pass, high-pass and band-pass filter. It also may have a transfer function which can be selected according to the application. For normal filtering in the frequency domain four pole Butterworth high-pass and low-pass filters are used. For use in the time domain a four pole Bessel low-pass filter is ideal inasmuch as it has a linear-phase characteristic which perserves the pulse wave shape.

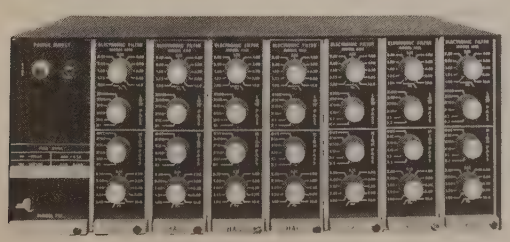
The phase and amplitude response of the Variable Electronic Filter will vary with each filter function (HP, LP, BP), with each filter characteristic (Butterworth, Bessel), and each filter cut-off frequency; so an exhaustive tabulation of amplitude and phase is not practical. However, with tabulation of the phase and amplitude response of a 4 pole Butterworth high-pass filter, a 4 pole Butterworth low-pass filter, and a 4 pole Bessel low-pass filter in 1/20 decade frequency steps, it is possible to obtain the amplitude and phase response for any filter function with cut-off frequencies in 1/10 decade steps. Further, many of the ITHACO Variable Electronic Filters have frequency cut-off steps of 1/10 decade (1/3 octave) so the resultant tabulations are directly applicable.

PHASE & AMPLITUDE RESPONSE OF 4 POLE BUTTERWORTH AND BESSEL FILTERS

The phase and amplitude response for a four pole Butterworth high-pass, 4 pole Butterworth low-pass, and 4 pole Bessel low-pass filter are tabulated in Chart I, II and III respectively. Referring to Chart I, the frequency is tabulated in the first eleven columns – each column corresponding to a 1/10 decade step in cut-off frequency – and the amplitude and phase in the last two columns.

If the filter cut-off frequency is one of the 1/10 decade increments listed at the top of the columns (1.0000, 1.2589, 1.5849, 1.9952, 2.5119, 3.1622, 3.9810, 5.0118, 6.3095, 7.9432, 10.000) or sufficiently close to these numbers such as the internationally preferred set of numbers used on the ITHACO Variable Electronic Filters (1.00, 1.25, 1.60, 2.00, 2.50, 3.15, 4.00, 5.00, 6.30, 8.00, 10.0), the phase and amplitude response can be determined directly from the charts. If the filter cut-off frequency is very different from these listed, the phase and amplitude response can be determined by multiplying each of the frequencies in Column 1 by the cut-off frequency and thereby obtaining a column of frequencies for the phase and amplitude response listed.

The normalized amplitude response for a 4 pole Butterworth high-pass, 4 pole Butterworth low-pass, and 4 pole Bessel low-pass filter is plotted in Figures 1 and 3 respectively and the normalized phase response is plotted in Figures 2 and 4 respectively. To determine the response for a particular cut-off frequency, the normalized frequency scale on the graph is multiplied by the filter cut-off frequency. For example, if the filter cut-off frequency is set to 2KHz, "1" on the normalized frequency scale will indicate 2 KHz, "2" on the normalized frequency scale will indicate 4 KHz, "5" on the normalized frequency scale will indicate 10 KHz, "0.5" on the normalized frequency scale will indicate 1 KHz, etc. In this manner a single curve can specify all filter settings.



TYPICAL ITHACO VARIABLE ELECTRONIC FILTERS

BAND–PASS FILTERS FORMED BY CASCADING HIGH–PASS AND LOW–PASS FILTERS

A band-pass filter can be formed by cascading a high-pass filter with a low-pass filter, and the resultant phase and amplitude response can be obtained from the individual filter responses by adding the amplitude in dB and the phase in degrees at the SAME frequency.

It is the requirement that the phase and amplitude response be added at the same frequency which dictated that the cut-off frequencies and the frequency increments be in compatable logarithmic steps. Referring to Chart I and Chart II, note each column contains the same frequencies (except at the extremes which are least significant). So the phase and amplitude response can be obtained by adding the response in Chart I to that in Chart II for any of the given filter settings.

EXAMPLE: For a Variable Electronic Filter set to:

High-Pass Setting, F_{HP} = 1.2589 KHz

Low-Pass Setting, F_{LP} = 3.1622 KHz

Band-Pass Center Freq., $F_O = \sqrt{(1.2589)\ (3.1622)}$ KHz

= 1.9952 KHz

Refer to Chart I, column 2 for the frequencies for a high-pass filter setting of 1.2589 KHz. Refer to Chart II, column 6 for the frequencies for a low-pass filter setting of 3.1622 KHz. The amplitude and phase information in Chart I is added to the amplitude and phase information in Chart II for the same frequency. Some of the information in Chart I and Chart II are tabulated below. Note, for 1.2589 KHz the high-pass amplitude response is –3.01 dB and the low-pass amplitude response is 0.0 dB so the resulting band-pass filter amplitude response is –3.01 dB. Similarly, for 1.2589 KHz, the high-pass phase response is 180.0 degrees and the low-pass phase response is –58.4 degrees, so the band-pass filter phase response is 121.6 degrees.

Chart IV, for example, is the overall response of a 4 pole Butterworth high-pass and low-pass filter cascaded with equal cut-off frequencies. This chart was obtained by assuming that the cut-off frequency for both filter sections was 1.0000 so the phase and amplitude response for each frequency in column 1 of Chart I was added to the corresponding phase and amplitude response for the same frequency in column 1 of Chart II.

Similarly Chart V is the overall response for a 4 pole Butterworth high-pass cascaded with a 4 pole Butterworth low-pass with the cut-off frequency separated by 1/10 decade. To obtain this tabulation the high-pass filter was assumed to have a cut-off frequency of 1.000 (column 1 of Chart I) and the low-pass filter was assumed to have a cut-off frequency of 1.2589 (column 2 of Chart II) and the resultant tabulation was obtained by looking up the amplitude and phase response for each frequency in column 1 of Chart I and adding it to the corresponding amplitude and phase response for the same frequency in column 2 of Chart II.

Similarly Chart VI and VII where obtained from Chart I and Chart II for 2/10 decade and 3/10 decade separation of the high and low-pass filters.

Figures 5 and 6 show the normalized amplitude and phase response of a band-pass filter formed by cascading 4 pole Butterworth filters for 0/10, 1/10, 2/10, 3/10 decade separation. Figure 7 shows the variation in filter gain (insertion loss) as the cut-off frequency of the high-pass and low-pass filters are separated. Figure 8 shows the normalized amplitude response with the insertion loss removed so the filter characteristics can be compared for different cut-off separations. Note that the filter response for no separation is only slightly different from those with 1/10 and 2/10 decade spearation, but the insertion loss is quite different which suggests that for many applications 2/10 decade separation is preferable. Figures 9 through 12 show families of band-pass filters with 1/10 decade steps in cut-off frequencies.

Chart VIII is an exact tabulation of –3dB frequencies center frequency, bandwidth, noise bandwidth, and filter gain for the internationally preferred set of frequency settings (1.00, 1.25, 1.60, 2.00, 2.50, 3.15, 4.00, 5.00, 6.30, 8.00) used in the ITHACO Variable Electronic Filter. This information is tabulated in a manner which permits it to be used for any combination of filter settings.

HIGH–PASS F_{HP} = 1.2589

CHART I

②	⑫	⑬
FREQ.	AMPLITUDE	PHASE
Hz	dB	DEGREES
1.2589	–3.01	180.0
1.4125	–1.46	153.5
1.5849	– .64	130.6
1.7783	– .27	112.1
1.9952	– .11	97.3
2.2387	– .04	85.1
2.5119	– .02	74.8
2.8183	– .01	66.0
3.1622	.00	58.4

LOW–PASS F_{LP} = 3.1622

CHART II

⑥	⑫	⑬
FREQ.	AMPLITUDE	PHASE
Hz	dB	DEGREES
1.2589	.00	– 58.4
1.4125	– .01	– 66.0
1.5849	– .02	– 74.8
1.7783	– .04	– 85.0
1.9952	– .11	– 97.3
2.2387	– .27	–112.1
2.5119	– .64	–130.6
2.8183	–1.46	–153.5
3.1622	–3.01	–180.0

BAND–PASS F_O = 1.9952

NEW CHART

FREQ.	AMPLITUDE	PHASE
Hz	dB	DEGREES
1.2589	–3.01	121.6
1.4125	–1.47	87.5
1.5849	– .66	55.8
1.7783	– .31	27.1
1.9952	– .22	0.0
2.2387	– .31	– 27.0
2.5119	– .66	– 55.8
2.8183	–1.47	– 87.5
3.1622	–3.01	–121.6

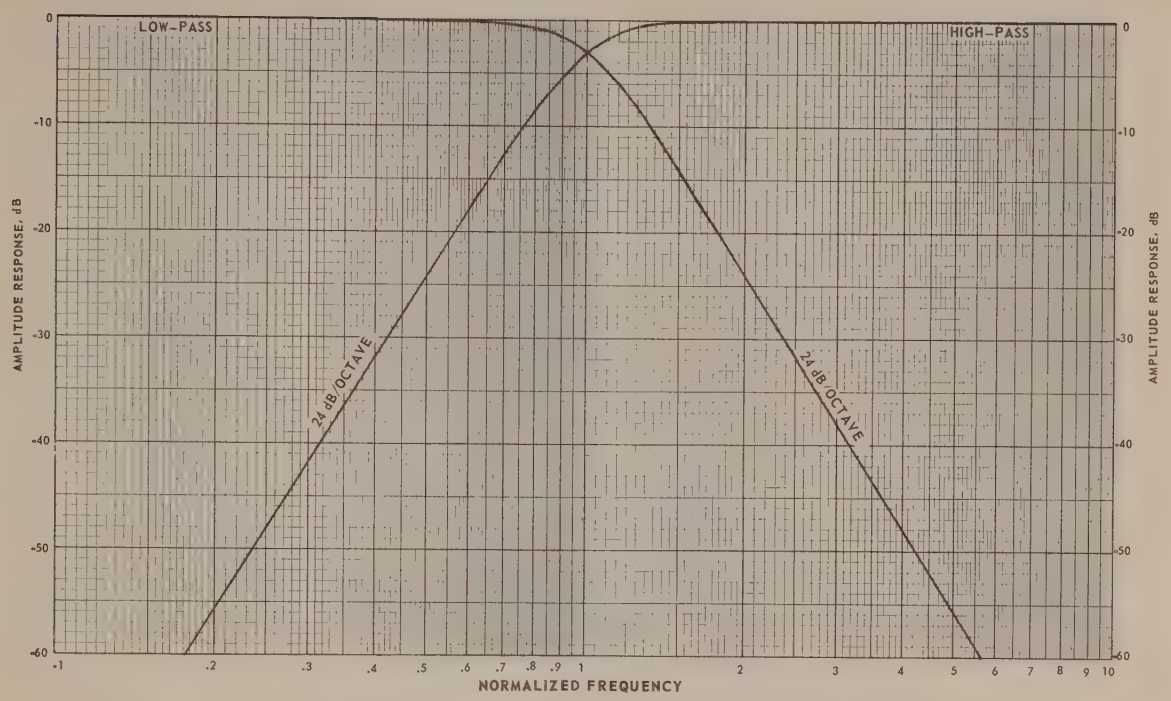


FIGURE 1 AMPLITUDE RESPONSE OF 4 POLE BUTTERWORTH FILTER

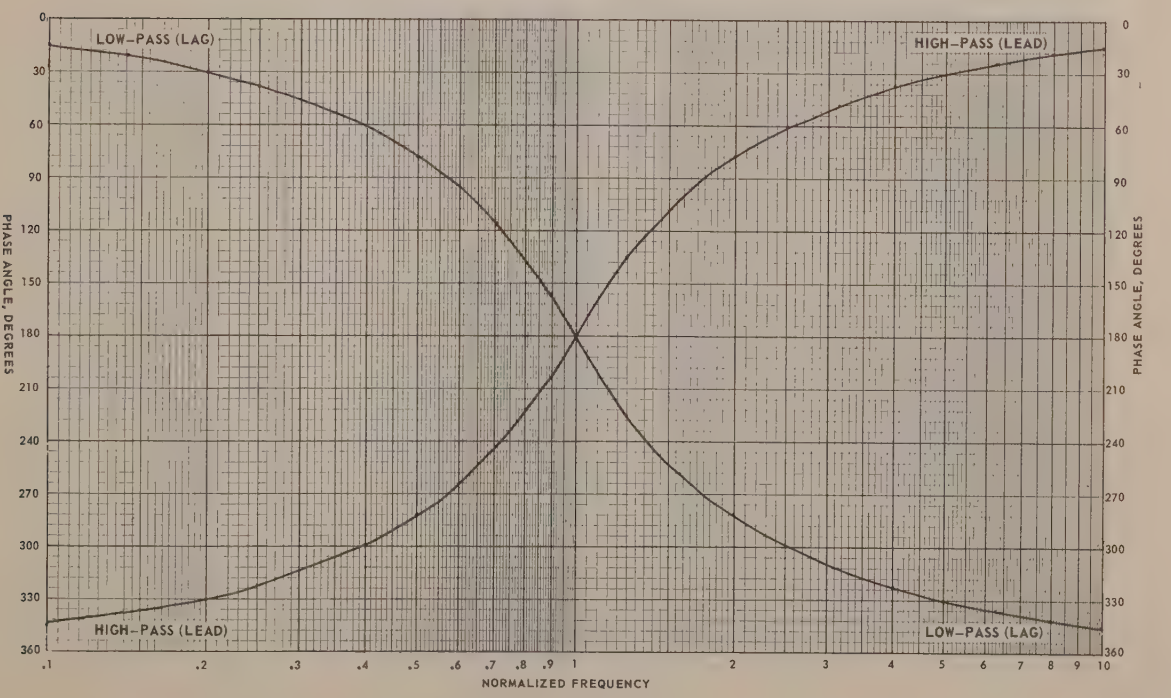


FIGURE 2 PHASE RESPONSE OF 4 POLE BUTTERWORTH FILTER

NORMALIZED AMPLITUDE RESPONSE OF A 4 POLE BESSEL LOW–PASS FILTER

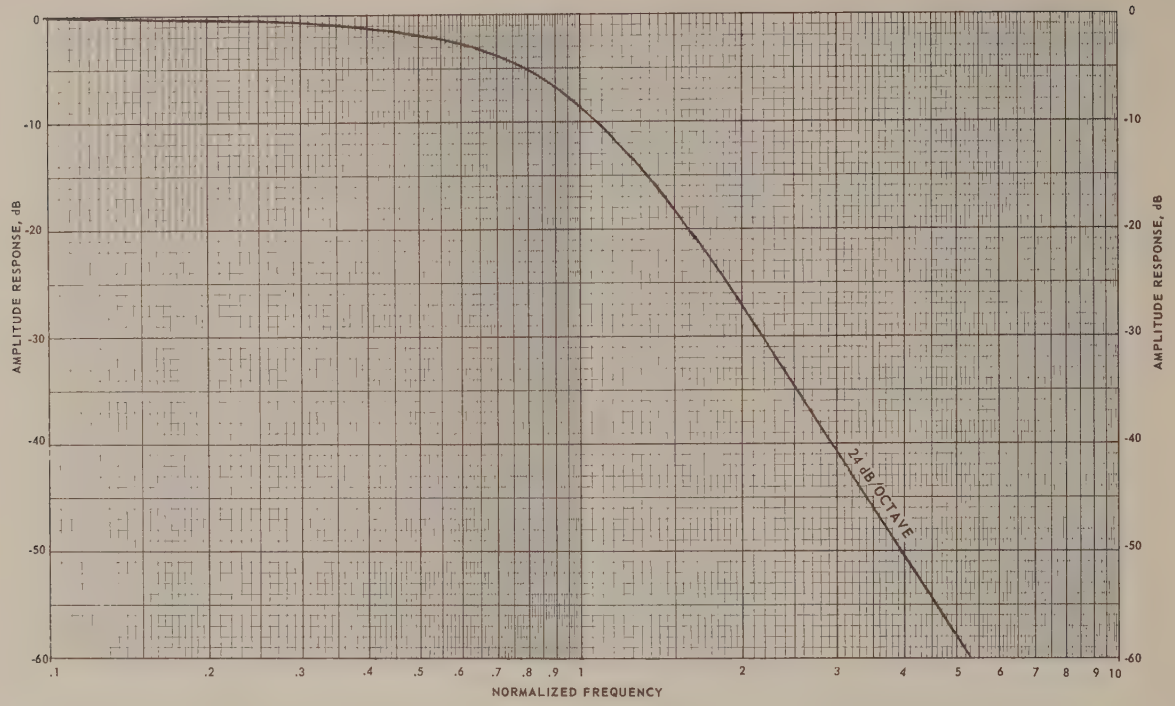


FIGURE 3 AMPLITUDE RESPONSE OF 4 POLE BESSEL FILTER

NORMALIZED PHASE RESPONSE OF A 4 POLE BESSEL LOW–PASS FILTER

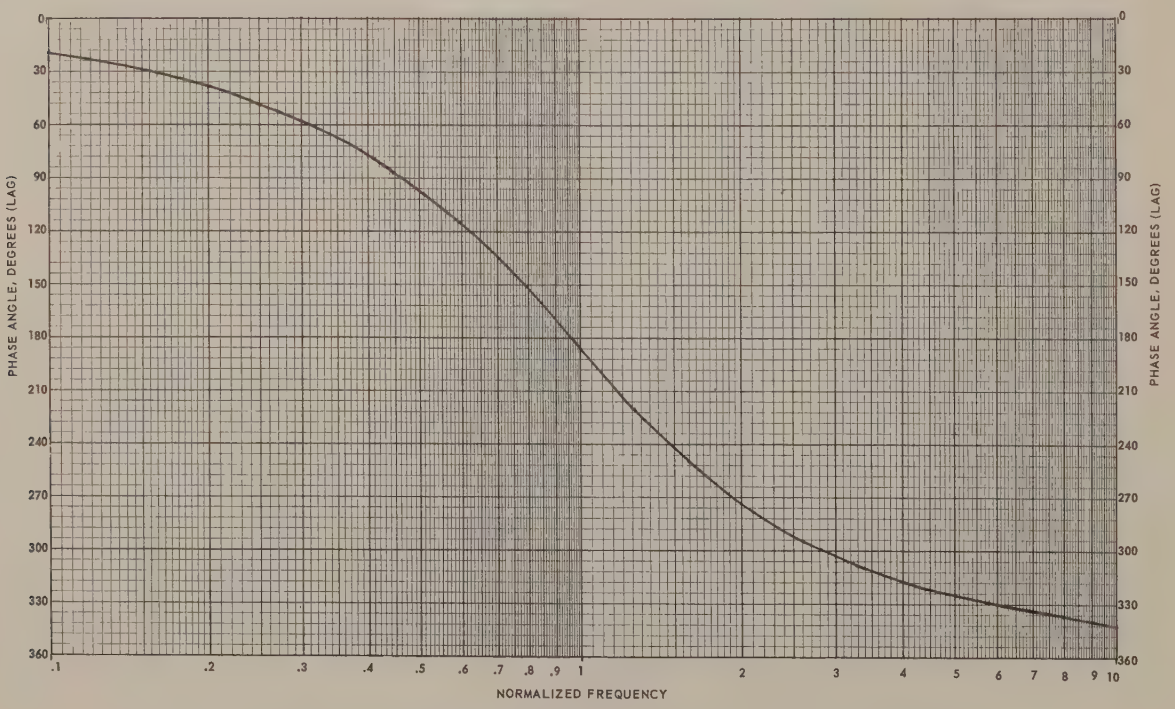


FIGURE 4 PHASE RESPONSE OF 4 POLE BESSEL FILTER

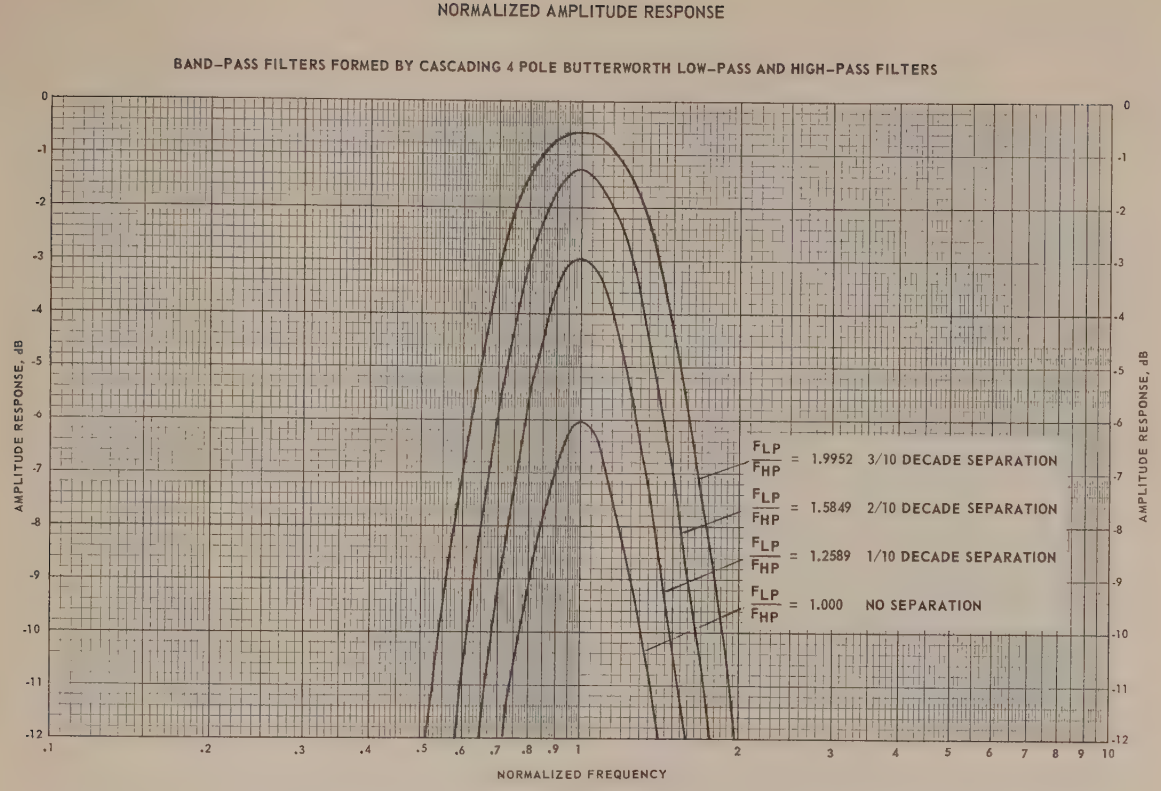

NORMALIZED AMPLITUDE RESPONSE
BAND-PASS FILTERS FORMED BY CASCADING 4 POLE BUTTERWORTH LOW-PASS AND HIGH-PASS FILTERS
AMPLITUDE RESPONSE, dB
NORMALIZED FREQUENCY
FLP/FHP = 1.9952 3/10 DECADE SEPARATION
FLP/FHP = 1.5849 2/10 DECADE SEPARATION
FLP/FHP = 1.2589 1/10 DECADE SEPARATION
FLP/FHP = 1.000 NO SEPARATION

FIGURE 5 AMPLITUDE RESPONSE OF BAND-PASS FILTERS FORMED BY CASCADING 4 POLE BUTTERWORTH FILTERS

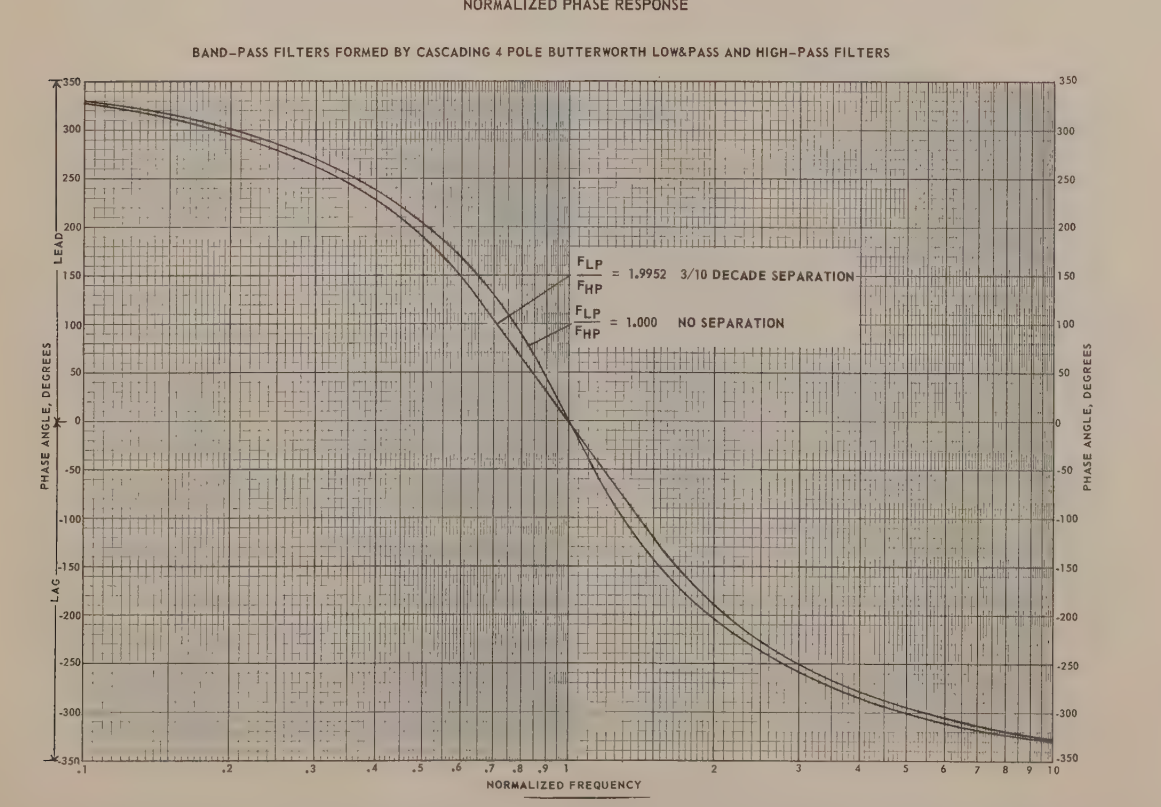

NORMALIZED PHASE RESPONSE
BAND-PASS FILTERS FORMED BY CASCADING 4 POLE BUTTERWORTH LOW&PASS AND HIGH-PASS FILTERS
PHASE ANGLE, DEGREES
LEAD
LAG
NORMALIZED FREQUENCY
FLP/FHP = 1.9952 3/10 DECADE SEPARATION
FLP/FHP = 1.000 NO SEPARATION

FIGURE 6 PHASE RESPONSE OF BAND-PASS FILTERS FORMED BY CASCADING 4 POLE BUTTERWORTH FILTERS

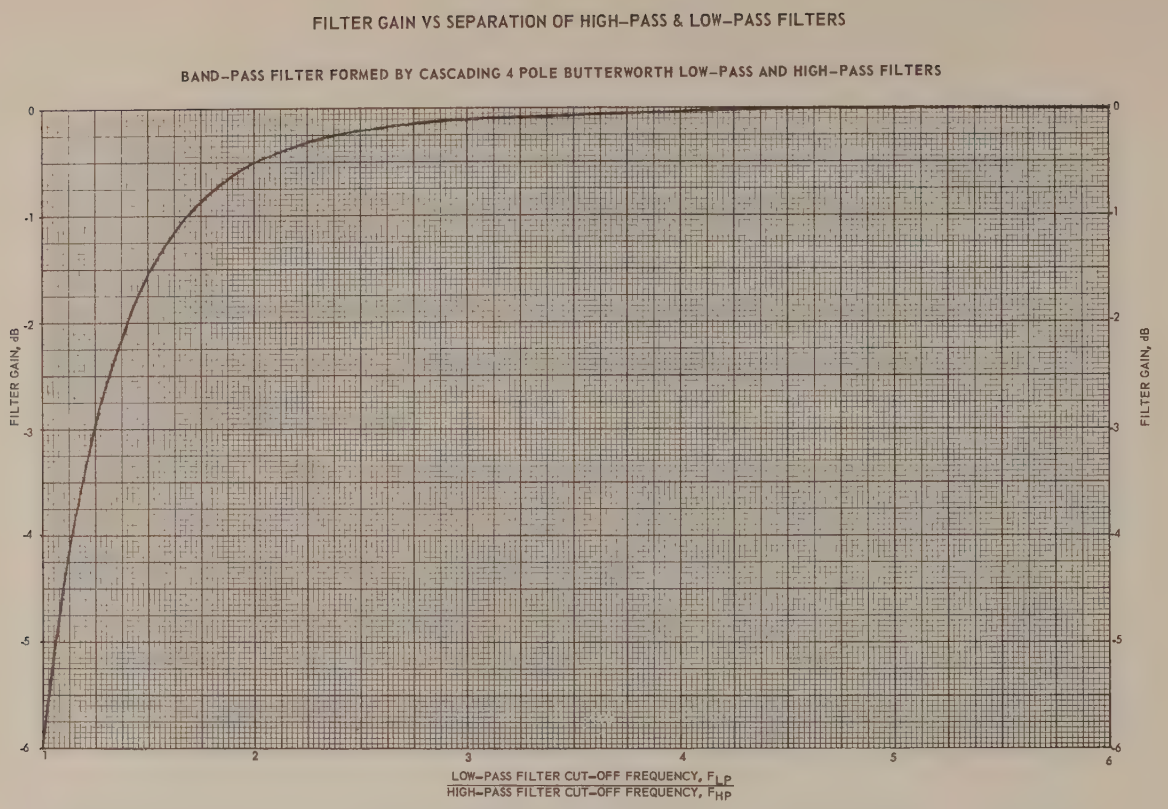


FIGURE 7 BAND–PASS FILTER GAIN VS SEPARATION OF HIGH & LOW–PASS FILTERS

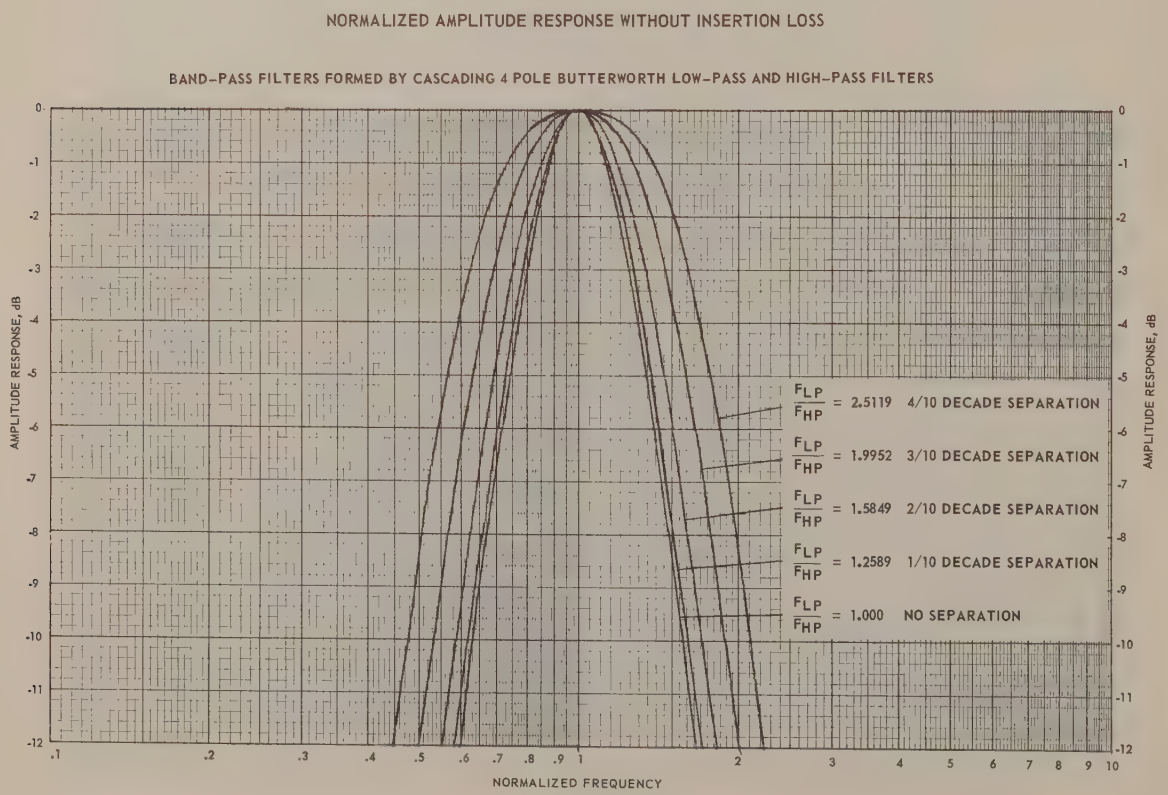


FIGURE 8 AMPLITUDE RESPONSE OF BAND–PASS FILTER WITHOUT INSERTION LOSS

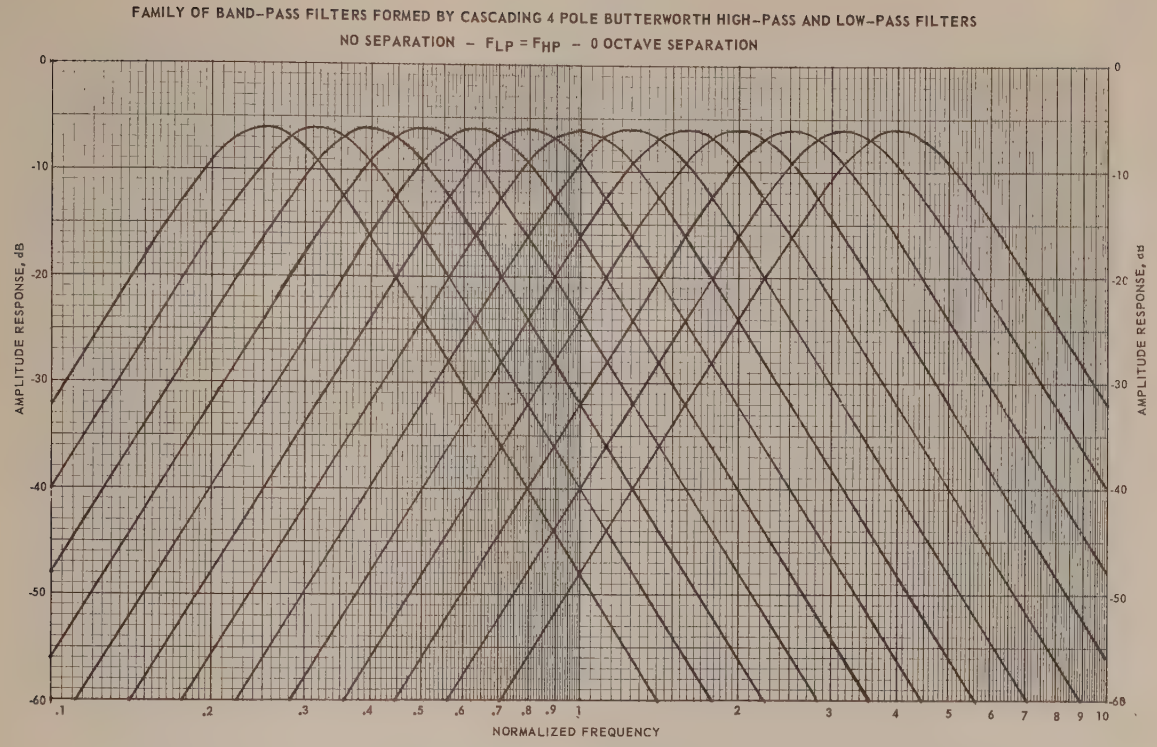


FIGURE 9 FAMILY OF BAND–PASS FILTERS WITH NO SEPARATION

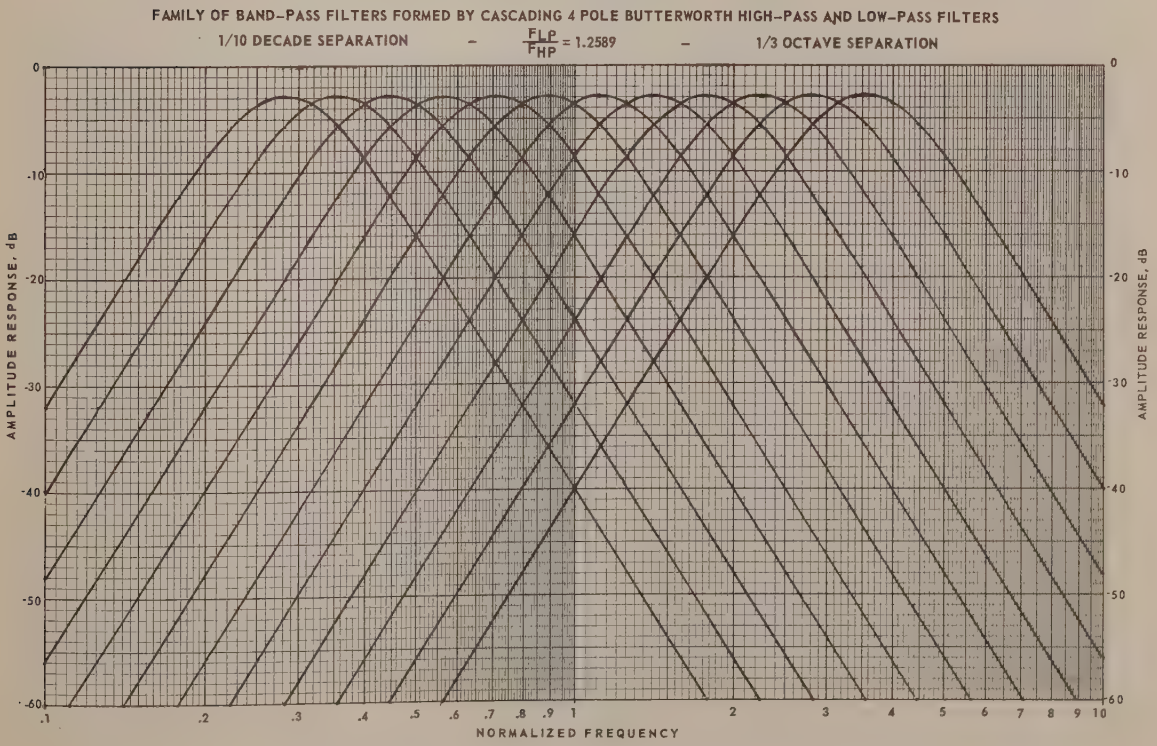


FIGURE 10 FAMILY OF BAND–PASS FILTERS WITH 1/10 DECADE SEPARATION

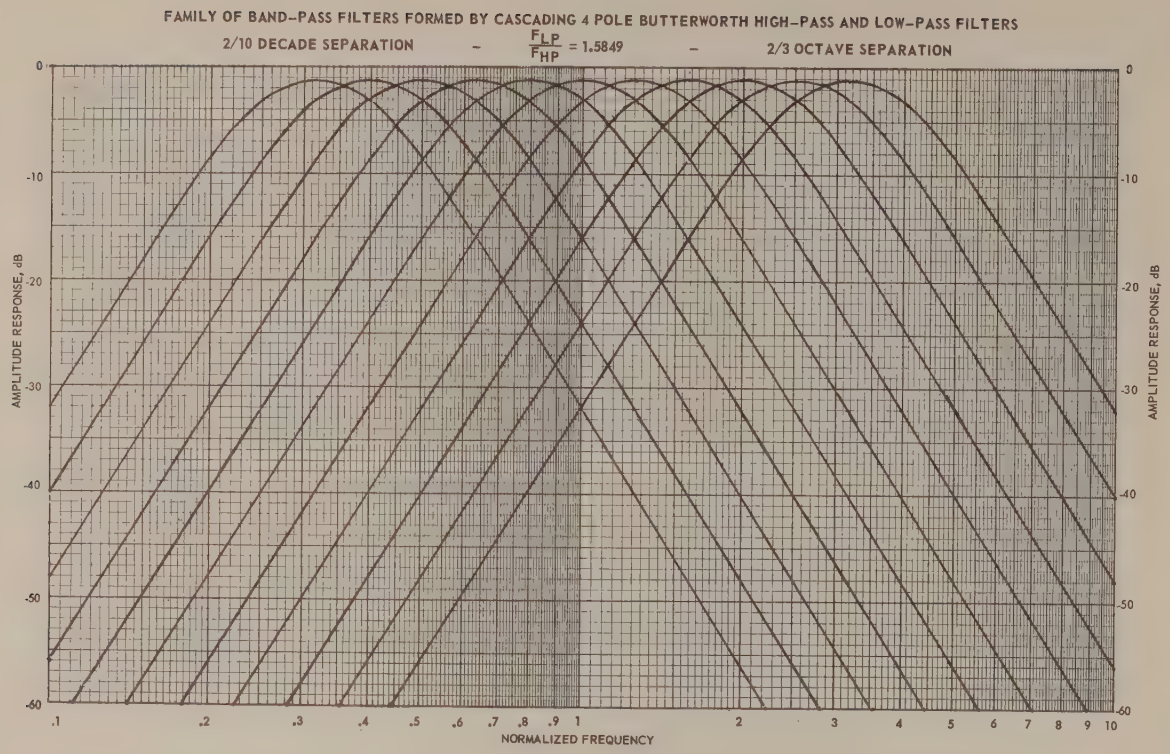


FIGURE 11 FAMILY OF BAND–PASS FILTERS WITH 2/10 DECADE SEPARATION

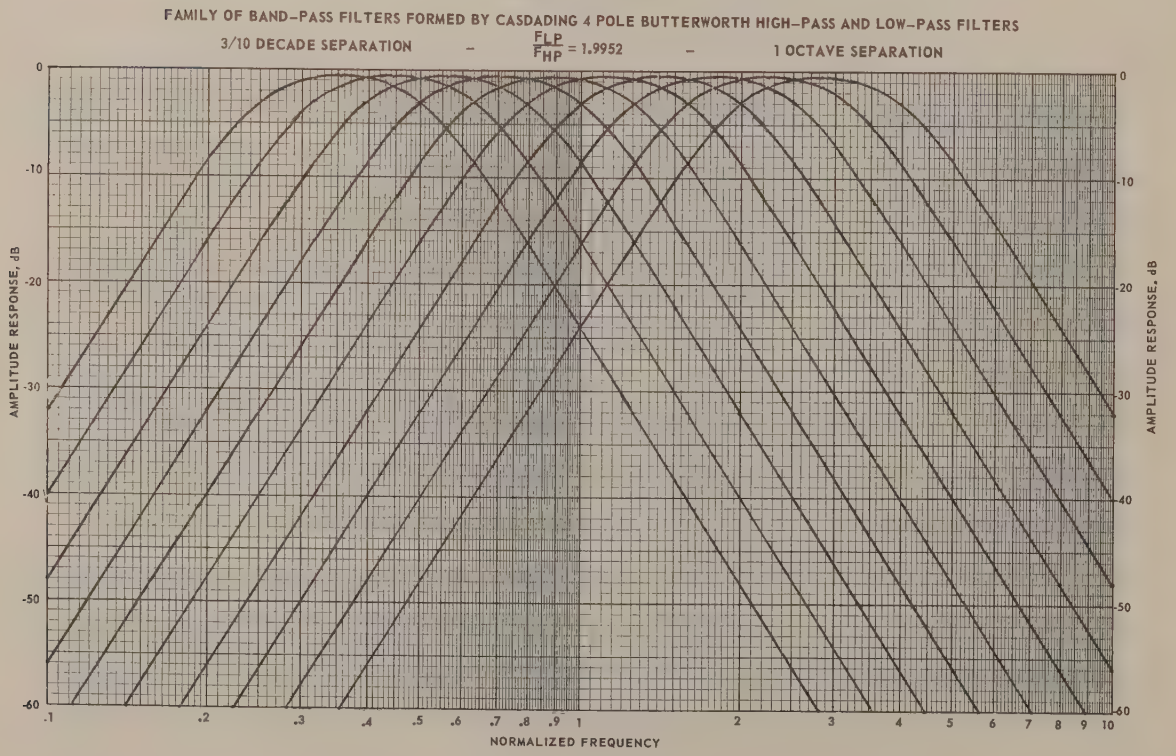


FIGURE 12 FAMILY OF BAND–PASS FILTERS WITH 3/10 DECADE SEPARATION

HIGH–PASS FILTER

BUTTERWORTH

PHASE & AMPLITUDE RESPONSE OF A 4 POLE BUTTERWORTH HIGH–PASS FILTER

FREQUENCY SETTING, Hz											AMPLITUDE RESPONSE dB	PHASE RESPONSE DEGREES
1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000		
FREQUENCY, Hz												
.0100	.0126	.0158	.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	-160.0	358.5
.0112	.0141	.0178	.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	-156.0	358.3
.0126	.0158	.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	-152.0	358.1
.0141	.0178	.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	-148.0	357.9
.0158	.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	-144.0	357.6
.0178	.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	-140.0	357.3
.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	-136.0	357.0
.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	-132.0	356.6
.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	-128.0	356.2
.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	-124.0	355.8
.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	-120.0	355.3
.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	-116.0	354.7
.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	-112.0	354.0
.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	-108.0	353.3
.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	-104.0	352 5
.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	-100.0	351.6
.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	- 96.0	350.5
.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	- 92.0	349.4
.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	- 88.0	348.1
.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	- 84.0	346.6
.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	- 80.0	345.0
.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	- 76.0	343.2
.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	- 72.0	341.1
.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	- 68.0	338.8
.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	- 64.0	336.2
.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	- 60.0	333.3
.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	- 56.0	330.0
.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	- 52.0	326.2
.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	- 48.0	322.1
.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	- 44.0	317.3
.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	- 40.0	312.0
.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	- 36.0	305.9
.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	- 32.00	298.9
.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	- 28.01	291.0
.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	- 24.02	281.8
.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	- 20.04	271.2
.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	- 16.11	258.6
.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	- 12.27	243.5
.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	- 8.64	225.4
.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	- 5.46	203.9
1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	- 3.01	180.0
1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	- 1.46	156.1
1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	- 0.64	134.6
1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	- 0.27	116.5
1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	0.11	101.4
1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	- 0.04	88.8
1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	- 0.02	78.2
2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	- 0.01	69.0
2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	0.00	61.1
2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	0.00	54.1
3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	0.00	48.0
3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	0.00	42.7
3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	0.00	38.0
4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	0.00	33.8
5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	0.00	30.0
5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	0.00	26.7
6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	0.00	23.8
7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	0.00	21.2
7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	0.00	18.9
8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	0.00	16.8
10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	0.00	15.0
11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	0.00	13.4
12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	0.00	11.9
14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	0.00	10.6
15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	0.00	9.4
17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	0.00	8.4
19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	0.00	7.5
22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	0.00	6.7
25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	0.00	6.0
28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	0.00	5.3
31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	0.00	4.7
35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	0.00	4.2
39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	0.00	3.8
44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	0.00	3.4
50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	0.00	3.0
56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	562.33	0.00	2.7
63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	630.95	0.00	2.4
70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	562.33	707.94	0.00	2.1
79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	630.95	794.32	0.00	1.9
89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	562.33	707.94	891.24	0.00	1.7
100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	630.95	794.32	1000.0	0.00	1.5

CHART II

LOW–PASS FILTER
BUTTERWORTH

PHASE & AMPLITUDE RESPONSE OF A 4 POLE BUTTERWORTH LOW–PASS FILTER

FREQUENCY SETTING, Hz											AMPLITUDE RESPONSE dB	PHASE RESPONSE DEGREES
1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000		
FREQUENCY, Hz												
.0100	.0126	.0158	.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	0.00	- 1.5
.0112	.0141	.0178	.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	0.00	- 1.7
.0126	.0158	.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	0.00	- 1.9
.0141	.0178	.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	0.00	- 2.1
.0158	.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	0.00	- 2.4
.0178	.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	0.00	- 2.7
.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	0.00	- 3.0
.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	0.00	- 3.4
.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	0.00	- 3.8
.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	0.00	- 4.2
.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	0.00	- 4.7
.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	0.00	- 5.3
.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	0.00	- 6.0
.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	0.00	- 6.7
.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	0.00	- 7.5
.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	0.00	- 8.4
.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	0.00	- 9.4
.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	0.00	- 10.6
.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	0.00	- 11.9
.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	0.00	- 13.4
.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	0.00	- 15.0
.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	0.00	- 16.8
.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	0.00	- 18.9
.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	0.00	- 21.2
.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	0.00	- 23.8
.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	0.00	- 26.7
.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	0.00	- 30.0
.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	0.00	- 33.8
.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	0.00	- 38.0
.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	0.00	- 42.7
.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	0.00	- 48.0
.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	0.00	- 54.1
.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	0.00	- 61.1
.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	- 0.01	- 69.0
.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	- 0.02	- 78.2
.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	- 0.04	- 88.8
.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	- 0.11	-101.4
.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	- 0.27	-116.5
.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	- 0.64	-134.6
.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	- 1.46	-156.1
1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	- 3.01	-180.0
1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	- 5.45	-203.9
1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	- 8.64	-225.4
1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	- 12.26	-243.5
1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	- 16.11	-258.6
1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	- 20.04	-271.2
1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	- 24.02	-281.8
2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	- 28.01	-291.0
2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	- 32.00	-298.9
2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	- 36.00	-305.9
3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	- 40.00	-312.0
3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	- 44.00	-317.3
3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	- 48.00	-322.1
4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	- 52.00	-326.2
5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	- 56.00	-330.0
5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	- 60.00	-333.3
6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	- 64.00	-336.2
7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	- 68.00	-338.8
7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	- 72.00	-341.1
8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	- 76.00	-343.2
10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	- 80.00	-345.0
11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	- 84.00	-346.6
12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	- 88.00	-348.1
14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	- 92.00	-349.4
15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	- 96.00	-350.5
17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	-100.00	-351.6
19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	-104.00	-352.5
22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	-108.00	-353.3
25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	-112.00	-354.0
28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	-116.00	-354.7
31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	-120.00	-355.3
35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	-124.00	-355.8
39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	-128.00	-356.2
44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	-132.00	-356.6
50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	-136.00	-357.0
56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	562.33	-140.00	-357.3
63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	630.95	-144.00	-357.6
70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	562.33	707.94	-148.00	-357.9
79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	630.95	794.32	-152.00	-358.1
89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	562.33	707.94	891.24	-156.00	-358.3
100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	630.95	794.32	1000.0	-160.00	-358.5

LOW-PASS FILTER

BESSEL — LINEAR PHASE — MAXIMAL FLAT TIME DELAY

PHASE & AMPLITUDE RESPONSE OF A 4 POLE BESSEL LOW-PASS FILTER

FREQUENCY SETTING, Hz											AMPLITUDE RESPONSE dB	PHASE RESPONSE DEGREES
1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000		
FREQUENCY, Hz												
.0100	.0126	.0158	.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	0.00	- 1.94
.0112	.0141	.0178	.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	0.00	- 2.18
.0126	.0158	.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	0.00	- 2.45
.0141	.0178	.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	0.00	- 2.74
.0158	.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	0.00	- 3.08
.0178	.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	0.00	- 3.45
.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	0.00	- 3.88
.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	0.00	- 4.35
.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	0.00	- 4.88
.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	- 0.01	- 5.47
.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	- 0.01	- 6.14
.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	- 0.01	- 6.89
.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	- 0.01	- 7.73
.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	- 0.01	- 8.68
.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	- 0.02	- 9.73
.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	- 0.02	- 10.92
.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	- 0.03	- 12.25
.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	- 0.04	- 13.75
.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	- 0.05	- 15.43
.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	- 0.06	- 17.31
.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	- 0.07	- 19.42
.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	- 0.09	- 21.79
.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	- 0.11	- 24.45
.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	- 0.14	- 27.43
.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	- 0.18	- 30.78
.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	- 0.23	- 34.54
.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	- 0.29	- 38.75
.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	- 0.36	- 43.48
.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	- 0.45	- 48.78
.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	- 0.57	- 54.74
.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	- 0.73	- 61.41
.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	- 0.92	- 68.91
.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	- 1.16	- 77.31
.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	- 1.48	- 86.73
.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	- 1.88	- 97.29
.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	- 2.41	-109.09
.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	- 3.09	-122.23
.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	- 3.98	-136.75
.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	- 5.15	-152.57
.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	- 6.67	-169.43
1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	- 8.58	-186.80
1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	- 10.91	-204.10
1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	- 13.64	-220.65
1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	- 16.69	-235.99
1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	- 20.00	-249.89
1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	- 23.50	-262.31
1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	- 27.13	273.32
2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	- 30.86	-283.06
2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	- 34.66	-291.67
2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	- 38.51	-299.28
3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	- 42.39	-306.01
3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	- 46.30	-311.98
3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	- 50.24	-317.27
4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	- 54.18	-321.96
5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	- 58.14	-326.13
5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	- 62.11	-329.84
6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	- 66.08	-333.14
7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	- 70.06	-336.07
7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	- 74.05	-338.68
8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	- 78.03	-341.01
10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	- 82.02	-343.08
11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	- 86.02	-344.92
12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	- 90.01	-346.56
14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	- 94.00	-348.03
15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	- 98.00	-349.33
17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	-102.00	-350.49
19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	-106.00	-351.52
22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	-109.99	-352.45
25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	-113.99	-353.27
28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	-117.99	-354.00
31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	-121.99	-354.65
35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	-125.99	-355.23
39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	-129.99	-355.75
44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	-133.99	-356.21
50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	-137.99	-356.63
56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	562.33	-141.99	-356.99
63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	630.95	-145.99	-357.32
70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	562.33	707.94	-149.99	-357.61
79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	630.95	794.32	-153.99	-357.87
89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	562.33	707.94	891.24	-157.99	-358.10
100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	630.95	794.32	1000.0	-161.99	-358.31

CHART IV

BAND–PASS FILTER

$F_{LP} = F_{HP} = F_O$

BAND–PASS FILTERS FORMED BY CASCADING 4 POLE BUTTERWORTH HIGH–PASS & LOW–PASS FILTERS

1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	CENTER FREQ.	
1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	L.P. SETTING	
1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	H.P. SETTING	
FREQUENCY, Hz											AMPLITUDE dB	PHASE DEGREES
.0100	.0126	.0158	.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	-160.0	357.0
.0112	.0141	.0178	.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	-156.0	356.6
.0126	.0158	.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	-152.0	356.2
.0141	.0178	.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	-148.0	355.8
.0158	.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	-144.0	355.3
.0178	.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	-140.0	354.7
.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	-136.0	354.0
.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	-132.0	353.3
.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	-128.0	352.5
.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	-124.0	351.6
.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	-120.0	350.5
.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	-116.0	349.4
.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	-112.0	348.1
.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	-108.0	346.6
.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	-104.0	345.0
.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	-100.0	343.2
.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	- 96.0	341.1
.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	- 92.0	338.8
.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	- 88.0	336.2
.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	- 84.0	333.3
.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	- 80.0	330.0
.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	- 76.0	326.3
.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	- 72.0	322.2
.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	- 68.0	317.6
.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	- 64.0	312.4
.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	- 60.0	306.5
.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	- 56.0	299.9
.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	- 52.0	292.5
.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	- 48.0	284.1
.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	- 44.0	274.6
.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	- 40.0	263.9
.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	- 36.0	251.7
.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	- 32.0	237.9
.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	- 28.02	222.0
.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	- 24.04	203.7
.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	- 20.08	182.3
.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	- 16.22	157.1
.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	- 12.54	127.0
.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	- 9.28	90.8
.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	- 6.92	47.8
1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	- 6.02	00.0
1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	- 6.92	- 47.8
1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	- 9.28	- 90.8
1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	- 12.54	- 127.0
1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	- 16.22	- 157.1
1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	- 20.08	-182.3
1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	- 24.04	-203.7
2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	- 28.02	-202.2
2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	- 32.0	- 237.9
2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	- 36.0	- 251.7
3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	- 40.0	- 263.9
3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	- 44.0	- 274.6
3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	- 48.0	- 284.1
4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	- 52.0	- 292.5
5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	- 56.0	- 299.9
5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	- 60.0	- 306.5
6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	- 64.0	- 312.4
7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	- 68.0	- 317.6
7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	- 72.0	- 322.2
8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	- 76.0	- 326.3
10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	- 80.0	- 330.0
11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	- 84.0	- 333.3
12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	- 88.0	- 336.2
14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	- 92.0	- 338.8
15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	- 96.0	- 341.1
17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	-100.0	- 343.2
19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	-104.0	- 345.0
22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	-108.0	- 346.6
25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	-112.0	- 348.1
28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	-116.0	- 349.4
31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	-120.0	- 350.5
35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	-124.0	- 351.6
39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	-128.0	- 352.5
44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	-132.0	- 353.3
50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	-136.0	- 354.0
56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	562.33	-140.0	- 354.7
63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	630.95	-144.0	- 355.3
70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	562.33	707.94	-148.0	- 355.8
79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	630.95	794.32	-152.0	- 356.2
89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	562.33	707.94	891.24	-156.0	- 356.6
100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	630.95	794.32	1000.0	-160.0	- 357.0

CHART V

BAND-PASS FILTER

1/10 DECADE SEPARATION — $\frac{F_{LP}}{F_{HP}} = 1.2589$ — 1/3 OCTAVE SEPARATION

BAND-PASS FILTERS FORMED BY CASCADING 4 POLE BUTTERWORTH HIGH-PASS & LOW-PASS FILTERS

1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	CENTER FREQ., F_O
1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	L.P. SETTING, F_{LP}
1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	H.P. SETTING, F_{HP}

FREQUENCY Hz											AMPLITUDE RESPONSE dB	PHASE RESPONSE DEGREES
.0100	.0126	.0158	.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	-160.0	357.3
.0112	.0141	.0178	.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	-156.0	357.0
.0126	.0158	.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	-152.0	356.6
.0141	.0178	.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	-148.0	356.2
.0158	.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	-144.0	355.7
.0178	.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	-140.0	355.2
.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	-136.0	354.6
.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	-132.0	354.0
.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	-128.0	353.3
.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	-124.0	352.4
.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	-120.0	351.5
.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	-116.0	350.5
.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	-112.0	349.3
.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	-108.0	348.0
.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	-104.0	346.5
.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	-100.0	344.9
.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	- 96.00	343.0
.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	- 92.00	341.0
.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	- 88.00	338.6
.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	- 84.00	336.0
.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	- 80.00	333.1
.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	- 76.00	329.8
.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	- 72.00	326.1
.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	- 68.00	322.0
.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	- 64.00	317.3
.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	- 60.00	312.0
.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	- 56.00	306.1
.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	- 52.00	299.5
.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	- 48.00	292.0
.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	- 44.00	283.6
.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	- 40.00	274.0
.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	- 36.00	263.2
.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	- 32.00	250.9
.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	- 28.01	236.9
.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	- 24.02	220.8
.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	- 20.05	202.2
.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	- 16.13	180.4
.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	- 12.30	154.7
.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	- 8.75	123.9
.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	- 5.72	87.4
1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	- 3.65	45.4
1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	- 2.92	00.0
1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	- 3.65	- 45.4
1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	- 5.72	- 87.4
1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	- 8.75	-123.9
1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	- 12.30	-154.7
1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	- 16.13	-180.4
2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	- 20.05	-202.2
2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	- 24.02	-220.8
2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	- 28.01	-236.9
3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	- 32.00	-250.9
3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	- 36.00	-263.2
3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	- 40.00	-274.0
4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	- 44.00	-283.6
5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	- 48.00	-292.0
5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	- 52.00	-299.5
6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	- 56.00	-306.1
7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	- 60.00	-312.0
7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	- 64.00	-317.3
8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	- 68.00	-322.0
10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	- 72.00	-326.1
11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	- 76.00	-329.8
12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	- 80.00	-333.1
14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	- 84.00	-336.0
15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	- 88.00	-338.6
17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	- 92.00	-341.0
19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	- 96.00	-343.0
22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	-100.0	-344.9
25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	-104.0	-346.5
28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	-108.0	-348.0
31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	-112.0	-349.3
35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	-116.0	-350.5
39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	-120.0	-351.5
44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	-124.0	-352.4
50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	-128.0	-353.3
56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	562.33	-132.0	-354.0
63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	630.95	-136.0	-354.6
70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	562.33	707.94	-140.0	-355.2
79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	630.95	794.32	-144.0	-355.7
89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	562.33	707.94	891.24	-148.0	-356.2
100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	630.95	794.32	1000.0	-152.0	-356.6

BAND–PASS FILTER

CHART VI

2/10 DECADE SEPARATION — $\frac{F_{LP}}{F_{HP}}$ — — 2/3 OCTAVE SEPARATION

BAND–PASS FILTERS FORMED BY CASCADING 4 POLE BUTTERWORTH HIGH–PASS & LOW–PASS FILTERS

1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	CENTER FREQ., F_O
1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	L.P. SETTING, F_{LP}
.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	H.P. SETTING, F_{HP}

FREQUENCY, Hz											AMPLITUDE RESPONSE dB	PHASE RESPONSE DEGREES
.0100	.0126	.0158	.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	-152.0	356.9
.0112	.0141	.0178	.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	-148.0	356.6
.0126	.0158	.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	-144.0	356.1
.0141	.0178	.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	-140.0	355.7
.0158	.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	-136.0	355.1
.0178	.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	-132.0	354.5
.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	-128.0	353.9
.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	-124.0	353.1
.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	-120.0	352.3
.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	-116.0	351.3
.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	-112.0	350.3
.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	-108.0	349.1
.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	-104.0	347.8
.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	-100.0	346.3
.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	- 96.0	344.6
.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	- 92.0	342.7
.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	- 88.0	340.6
.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	- 84.0	338.2
.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	- 80.0	335.6
.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	- 76.0	332.6
.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	- 72.0	329.2
.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	- 68.0	325.4
.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	- 64.0	321.2
.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	- 60.0	316.4
.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	- 56.0	311.1
.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	- 52.0	305.0
.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	- 48.0	298.2
.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	- 44.0	290.6
.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	- 40.0	281.9
.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	- 36.0	272.1
.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	- 32.0	261.0
.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	- 28.01	248.3
.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	- 24.02	233.8
.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	- 20.04	217.0
.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	- 16.11	197.5
.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	- 12.28	174.5
.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	- 8.66	147.2
.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	- 5.50	115.1
.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	- 3.12	78.6
.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	- 1.73	39.6
1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	- 1.28	00.0
1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	- 1.73	- 39.6
1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	- 3.12	- 78.6
1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	- 5.50	-115.1
1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	- 8.66	-147.2
1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	- 12.27	-174.5
1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	- 16.11	-197.5
2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	- 20.04	-217.0
2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	- 24.02	-233.8
2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	- 28.01	-248.3
3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	- 32.0	-261.0
3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	- 36.0	-272.1
3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	- 40.0	-281.9
4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	- 44.0	-290.6
5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	- 48.0	-298.2
5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	- 52.0	-305.0
6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	- 56.0	-311.1
7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	- 60.0	-316.4
7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	- 64.0	-321.2
8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	- 68.0	-325.4
10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	- 72.0	-329.2
11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	- 76.0	-332.6
12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	- 80.0	-335.6
14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	- 84.0	-338.2
15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	- 88.0	-340.6
17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	- 92.0	-342.7
19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	- 96.0	-344.6
22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	-100.0	-346.3
25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	-104.0	-347.8
28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	-108.0	-349.1
31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	-112.0	-350.3
35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	-116.0	-351.3
39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	-120.0	-352.3
44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	-124.0	-353.1
50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	-128.0	-353.9
56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	562.33	-132.0	-354.5
63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	630.95	-136.0	-355.1
70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	562.33	707.94	-140.0	-355.7
79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	630.95	794.32	-144.0	-356.1
89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	562.33	707.94	891.24	-148.0	-356.6
100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	630.95	794.32	1000.0	-152.0	-356.9

BAND–PASS FILTER

3/10 DECADE SEPARATION — $\frac{F_{LP}}{F_{HP}} = 1.9952$ — 1 OCTAVE SEPARATION

CHART VII

BAND–PASS FILTERS FORMED BY CASCADING 4 POLE BUTTERWORTH HIGH–PASS & LOW–PASS FILTERS

1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	CENTER FREQ., F_O
1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	L.P. SETTING, F_{LP}
.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	H.P. SETTING, F_{HP}

FREQUENCY, Hz											AMPLITUDE RESPONSE dB	PHASE RESPONSE DEGREES
.0100	.0126	.0158	.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	-152.0	357.2
.0112	.0141	.0178	.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	-148.0	356.8
.0126	.0158	.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	-144.0	356.4
.0141	.0178	.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	-140.0	356.0
.0158	.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	-136.0	355.5
.0178	.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	-132.0	355.0
.0200	.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	-128.0	354.4
.0224	.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	-124.0	353.7
.0251	.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	-120.0	352.9
.0282	.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	-116.0	352.0
.0316	.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	-112.0	351.1
.0355	.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	-108.0	350.0
.0398	.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	-104.0	348.7
.0447	.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	-100.0	347.4
.0501	.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	- 96.0	345.8
.0562	.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	- 92.0	344.1
.0631	.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	- 88.00	342.1
.0708	.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	- 84.00	340.0
.0794	.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	- 80.00	337.5
.0891	.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	- 76.00	334.7
.1000	.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	- 72.00	331.7
.1122	.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	- 68.00	328.2
.1259	.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	- 64.00	324.3
.1413	.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	- 60.00	319.9
.1585	.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	- 56.00	315.0
.1778	.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	- 52.00	309.4
.1995	.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	- 48.00	303.2
.2239	.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	- 44.00	296.1
.2512	.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	- 40.00	288.1
.2818	.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	- 36.00	279.1
.3162	.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	- 32.00	268.9
.3548	.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	- 28.01	257.2
.3981	.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	- 24.02	243.9
.4467	.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	- 20.04	228.5
.5012	.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	- 16.11	210.5
.5623	.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	- 12.26	189.4
.6310	.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	- 8.64	164.3
.7079	.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	- 5.46	134.9
.7943	1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	- 3.03	101.8
.8912	1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	- 1.50	67.3
1.0000	1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	- 0.75	33.2
1.1220	1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	- 0.54	00.0
1.2589	1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	- 0.75	- 33.2
1.4125	1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	- 1.50	- 67.3
1.5849	1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	- 3.03	-101.8
1.7783	2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	- 5.46	-134.9
1.9952	2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	- 8.64	-164.3
2.2387	2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	- 12.26	-189.4
2.5119	3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	- 16.11	-210.5
2.8183	3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	- 20.04	-228.5
3.1622	3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	- 24.02	-243.9
3.5481	4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	- 28.01	-257.2
3.9810	5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	- 32.00	-268.9
4.4668	5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	- 36.00	-279.1
5.0118	6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	- 40.00	-288.1
5.6233	7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	- 44.00	-296.1
6.3095	7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	- 48.00	-303.2
7.0794	8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	- 52.00	-309.4
7.9432	10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	- 56.00	-315.0
8.9124	11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	- 60.00	-319.9
10.000	12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	- 64.00	-324.3
11.220	14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	- 68.00	-328.2
12.589	15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	- 72.00	-331.7
14.125	17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	- 76.00	-334.7
15.849	19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	- 80.00	-337.5
17.783	22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	- 84.00	-340.0
19.952	25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	- 88.00	-342.1
22.387	28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	- 92.00	-344.1
25.119	31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	-96.00	-345.8
28.183	35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	-100.0	-347.4
31.622	39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	-104.0	-348.7
35.481	44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	-108.0	-350.0
39.810	50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	-112.0	-351.1
44.668	56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	-116.0	-352.0
50.118	63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	-120.0	-352.9
56.233	70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	562.33	-124.0	-353.7
63.095	79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	630.95	-128.0	-354.4
70.794	89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	562.33	707.94	-132.0	-355.0
79.432	100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	630.95	794.32	-136.0	-355.5
89.124	112.20	141.25	177.83	223.87	281.83	354.81	446.68	562.33	707.94	891.24	-140.0	-356.0
100.00	125.89	158.49	199.52	251.19	316.22	398.10	501.18	630.95	794.32	1000.0	-144.0	-356.4

HIGH-PASS FILTER (LOW-FREQUENCY ROLLOFF)

NORMAL (BUTTERWORTH): −3 dB AND +180° AT THE HIGH-PASS FREQUENCY SETTING
PULSE (BUTTERWORTH): −3 dB AND +180° AT THE HIGH-PASS FREQUENCY SETTING

LOW-PASS FILTER (HIGH-FREQUENCY ROLLOFF)

NORMAL (BUTTERWORTH): −3 dB and −180° AT THE LOW-PASS FREQUENCY SETTING
PULSE (BESSEL): −8.6 dB and −187° AT THE LOW-PASS FREQUENCY SETTING
DC COUPLED: SET HIGH-PASS MULTIPLIER TO OUT

BAND-PASS FILTER (NORMAL MODE ONLY)

WHEN THE LOW-PASS FILTER SETTING, F_{LP} (HIGH FREQUENCY ROLLOFF) DIVIDED BY THE HIGH-PASS FILTER SETTING, F_{HP} (LOW-FREQUENCY ROLLOFF) IS LESS THAN 4, THE CHART BELOW MUST BE CONSULTED FOR BAND-PASS FILTER CHARACTERISTICS. (FOR USERS CONVENIENCE, THE FILTER CHARACTERISTICS HAVE BEEN TABULATED FOR $F_{LP}/F_{HP} \leq 10$)

DIRECTIONS:

$\frac{F_{LP}}{F_{HP}} > 4$

- UPPER −3 dB FREQUENCY = LOW-PASS CUTOFF FREQUENCY
- CENTER FREQUENCY = $\sqrt{F_{HP} \cdot F_{LP}}$
- LOWER −3 dB FREQUENCY = HIGH-PASS CUTOFF FREQUENCY
- −3 dB BANDWIDTH = $F_{LP} - F_{HP}$
- NOISE BANDWIDTH = $1.025 (F_{LP} - F_{HP})$
- FILTER GAIN = 0.0 dB

$\frac{F_{LP}}{F_{HP}} \leq 4$

1. DIVIDE THE CUTOFF FREQUENCY SETTINGS BY HIGH-PASS MULTIPLIER TO OBTAIN NORMALIZED SETTINGS.
2. OBTAIN THE FILTER GAIN AND NORMALIZED FREQUENCIES FROM TABLE USING NORMALIZED SETTINGS.
3. MULTIPLY NORMALIZED FREQUENCIES OBTAINED FROM TABLE BY HIGH-PASS MULTIPLIER.

EXAMPLE:
HIGH-PASS CUTOFF FREQUENCY, Hz = 6.30×10^3 (Divide by High-Pass Multiplier) → NORMALIZED HIGH-PASS SETTING = 6.30
LOW-PASS CUTOFF FREQUENCY, Hz = 1.00×10^4 → NORMALIZED LOW-PASS SETTING = 10.0

	NORMALIZED (From Table)	ACTUAL (Multiply by High-Pass Multiplier)
UPPER −3 dB FREQUENCY, Hz	10.70	1.07×10^4
CENTER FREQUENCY, Hz	7.937	7.937×10^3
LOWER −3 dB FREQUENCY, Hz	5.932	5.932×10^3
−3 dB BANDWIDTH, Hz	4.768	4.768×10^3
NOISE BANDWIDTH, Hz	5.339	5.339×10^3
FILTER GAIN, dB	−1.23	−1.23 (Gain not normalized)

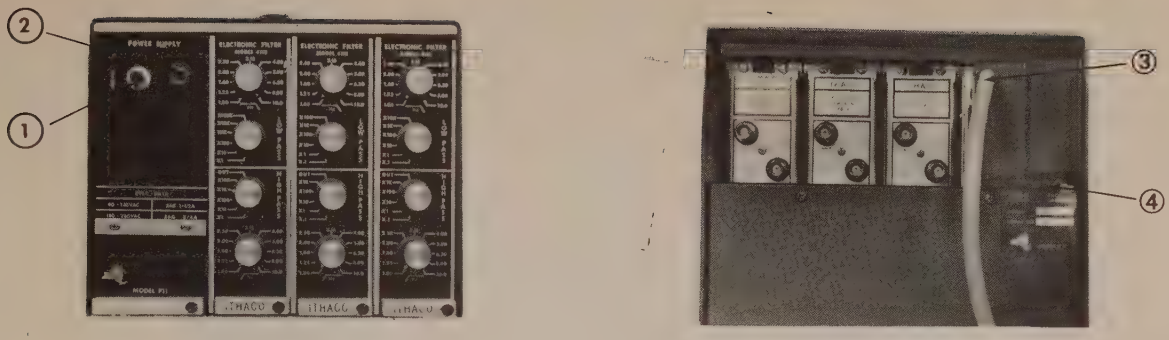
NORMALIZED HIGH-PASS SETTING		NORMALIZED LOW-PASS SETTING																		
		1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	25.0	31.5	40.0	50.0	63.0	80.0	100
1.00	UPPER −3 dB FREQ., Hz	1.245	1.418	1.699	2.057	2.530	3.165	4.000	5.000	6.300	8.000	10.00	12.50	16.00	20.00	25.00	31.50	40.00	50.00	63.00	80.00	100.0
	CENTER FREQ., Hz	1.000	1.118	1.265	1.414	1.581	1.774	2.000	2.236	2.510	2.828	3.162	3.536	4.000	4.472	5.000	5.612	6.325	7.071	7.937	8.944	10.00
	LOWER −3 dB FREQ., Hz	0.803	0.881	0.942	0.972	0.988	0.995	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	−3 dB BANDWIDTH, Hz	0.442	0.537	0.757	1.085	1.542	2.170	3.002	4.000	5.300	7.000	9.000	11.50	15.00	19.00	24.00	30.50	39.00	49.00	62.00	79.00	99.00
	NOISE BANDWIDTH, Hz	.513	.612	.848	1.163	1.620	2.252	3.105	4.097	5.414	7.178	9.226	11.79	15.38	19.48	24.60	31.26	39.99	50.23	63.53	81.00	101.5
	FILTER GAIN, dB	−6.02	−2.98	−1.23	−0.53	−0.22	−0.09	−0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.25	UPPER −3 dB FREQ., Hz		1.556	1.773	2.124	2.571	3.163	3.956	5.000	6.300	8.000	10.00	12.50	16.00	20.00	25.00	31.50	40.00	50.00	63.00	80.00	100.0
	CENTER FREQ., Hz		1.250	1.414	1.581	1.768	1.984	2.236	2.500	2.806	3.162	3.536	3.953	4.472	5.000	5.590	6.275	7.071	7.906	8.874	10.00	11.18
	LOWER −3 dB FREQ., Hz		1.004	1.101	1.177	1.215	1.235	1.245	1.247	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250
	−3 dB BANDWIDTH, Hz		0.552	0.672	0.947	1.356	1.928	2.711	3.753	5.050	6.750	8.750	11.25	14.75	18.75	23.75	30.25	38.75	48.75	61.75	78.75	98.75
	NOISE BANDWIDTH, Hz		.641	.766	1.059	1.454	2.025	2.815	3.877	5.176	6.919	8.974	11.53	15.12	19.21	24.35	31.01	39.72	49.95	63.31	80.72	101.3
	FILTER GAIN, dB		−6.02	2.98	−1.23	−0.53	−0.22	−0.09	−0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.60	UPPER −3 dB FREQ., Hz			1.992	2.269	2.718	3.291	4.048	5.064	6.400	8.000	10.00	12.50	16.00	20.00	25.00	31.50	40.00	50.00	63.00	80.00	100.0
	CENTER FREQ., Hz			1.600	1.789	2.000	2.245	2.530	2.828	3.175	3.578	4.000	4.472	5.060	5.657	6.325	7.099	8.000	8.944	10.04	11.31	12.65
	LOWER −3 dB FREQ., Hz			1.284	1.410	1.506	1.556	1.581	1.592	1.597	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600
	−3 dB BANDWIDTH, Hz			0.708	0.859	1.212	1.735	2.467	3.472	4.803	6.400	8.400	10.90	14.40	18.40	23.40	29.90	38.40	48.40	61.40	78.40	98.40
	NOISE BANDWIDTH, Hz			.821	.979	1.357	1.860	2.591	3.602	4.966	6.561	8.610	11.17	14.76	18.86	23.99	30.65	39.36	49.60	62.95	80.35	100.8
	FILTER GAIN, dB			−6.02	−2.98	1.23	−0.53	−0.22	−0.09	−0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	UPPER −3 dB FREQ., Hz				2.480	2.836	3.398	4.113	5.060	6.330	8.000	10.00	12.50	16.00	20.00	25.00	31.50	40.00	50.00	63.00	80.00	100.0
	CENTER FREQ., Hz				2.000	2.236	2.510	2.828	3.162	3.550	4.000	4.472	5.000	5.657	6.325	7.071	7.937	8.944	10.00	11.22	12.65	14.14
	LOWER −3 dB FREQ., Hz				1.606	1.762	1.882	1.945	1.976	1.990	1.996	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
	−3 dB BANDWIDTH, Hz				0.874	1.074	1.516	2.168	3.084	4.340	6.004	8.000	10.50	14.00	18.00	23.00	29.50	38.00	48.00	61.00	78.00	98.00
	NOISE BANDWIDTH, Hz				1.026	1.225	1.696	2.325	3.240	4.503	6.209	8.204	10.76	14.35	18.45	23.58	30.23	38.95	49.20	62.52	79.98	100.5
	FILTER GAIN, dB				−6.02	−2.98	−1.23	−0.53	−0.22	−0.09	−0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.50	UPPER −3 dB FREQ., Hz					3.113	3.545	4.247	5.142	6.325	7.913	10 00	12.50	16.00	20.00	25.00	31.50	40.00	50.00	63.00	80.00	100.0
	CENTER FREQ., Hz					2.500	2.806	3.162	3.536	3.969	4.472	5.000	5 590	6.325	7.071	7.906	8.874	10 00	11 18	12.55	14.14	15 81
	LOWER −3 dB FREQ., Hz					2.008	2.203	2.354	2.431	2.470	2.487	2.495	2.500	2.500	2.500	2.500	2.500	2.500	2.500	2.500	2.500	2.500
	−3 dB BANDWIDTH, Hz					1 105	1.342	1.893	2.711	3.855	5.426	7.505	10.00	13.50	17.50	22.50	29 00	37.50	47.50	60.50	77.50	97.50
	NOISE BANDWIDTH, Hz					1.282	1.531	2.246	2.907	4.050	5.630	7.754	10 24	13.84	17.95	23.07	29.72	38.46	48.70	62.02	79.43	99.88
	FILTER GAIN, dB					−6.02	−2 98	−1.23	−0.53	0.22	−0.09	−0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.15	UPPER −3 dB FREQ., Hz						3.921	4.467	5.352	6.478	7.970	9.970	12.60	16.00	20.00	25.00	31.50	40.00	50.00	63.00	80.00	100 0
	CENTER FREQ., Hz						3.150	3.550	3.969	4.455	5.020	5.612	6 275	7.099	7.937	8.874	9.961	11.22	12.55	14.09	15.87	17.75
	LOWER −3 dB FREQ., Hz						2.523	2.775	2.966	3.063	3.144	3.146	3.148	3.150	3.150	3.150	3.150	3.150	3.150	3.150	3.150	3.150
	−3 dB BANDWIDTH, Hz						1.398	1.692	2.386	3.415	4.826	6.824	9.452	12.85	16.85	21.85	28.35	36.85	46.85	59.85	76.85	96.85
	NOISE BANDWIDTH, Hz						1.616	1.930	2.670	3.664	5.105	7.096	9.772	13.17	17.27	22.40	29.07	37.76	48.03	61.38	78.80	99.21
	FILTER GAIN, dB						−6.02	−2 98	−1.23	− 0.53	−0.22	−0.09	−0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00	UPPER −3 dB FREQ., Hz							4.980	5.672	6.796	8.226	10.12	12.66	16.00	20.00	25.00	31.50	40.00	50.00	63.00	80.00	100 0
	CENTER FREQ., Hz							4.000	4.472	5.020	5.657	6.325	7.071	8.000	8.944	10.00	11.22	12.65	14.14	15.87	17.89	20.00
	LOWER −3 dB FREQ., Hz							3.212	3.524	3.766	3.890	3.952	3.980	3.992	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
	−3 dB BANDWIDTH, Hz							1.768	2.148	3.030	4 336	6.168	8.680	12.01	16.00	21.00	27.50	36.00	46.00	59.00	76.00	96.00
	NOISE BANDWIDTH, Hz							2.051	2.449	3.392	4.651	6.479	9.005	12.42	16.41	21.53	28.19	36.90	47.15	60.46	77.89	98.40
	FILTER GAIN, dB							−6.02	−2.98	−1.23	0.53	−0.22	−0.09	−0.03	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0.00
5.00	UPPER −3 dB FREQ., Hz								6.225	7.090	8.495	10.28	12.65	16.08	20.00	25.00	31.50	40.00	50.00	63.00	80.00	100.0
	CENTER FREQ., Hz								5.000	5.612	6.325	7.071	7.906	8.944	10.00	11.18	12.55	14.14	15.81	17.75	20.00	22.36
	LOWER −3 dB FREQ., Hz								4.015	4.405	4.708	4.862	4.940	4.975	4.990	5.000	5.000	5.000	5.000	5.000	5.000	5.000
	−3 dB BANDWIDTH, Hz								2.210	2.685	3.787	5.418	7.710	11.11	15.01	20.00	26.50	35.00	45.00	58.00	75.00	95 00
	NOISE BANDWIDTH, Hz								2.564	3.062	4.241	5.814	8.100	11.26	15.51	20.49	27.07	35.89	46.13	59.43	76.91	97.39
	FILTER GAIN, dB								−6.02	−2.98	− 1.23	− 0.53	− 0.22	−0.09	−0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6.30	UPPER −3 dB FREQ., Hz									7.843	8.933	10.70	12.96	15.94	19.94	25.20	31.50	40.00	50.00	63.00	80.00	100 0
	CENTER FREQ., Hz									6.300	7.099	7.937	8.874	10.04	11.22	12.55	14.09	15.87	17.75	19.92	22.45	25.10
	LOWER −3 dB FREQ., Hz									5.059	5.550	5.932	6.126	6.224	6.268	6.287	6.300	6.300	6.300	6.300	6.300	6.300
	−3 dB BANDWIDTH, Hz									2.784	3.383	4.768	6.834	9.716	13.67	18.91	25.20	33.70	43.70	56.70	73.70	93.70
	NOISE BANDWIDTH, Hz									3.232	3.898	5.339	7.328	10.21	14.19	19.54	25.82	34.54	44.79	58.14	75.51	96.05
	FILTER GAIN, dB									−6 02	− 2.98	−1.23	− 0.53	− 0.22	−0.09	− 0.03	0.00	0.00	0.00	0.00	0.00	0.00
8.00	UPPER −3 dB FREQ., Hz										9.960	11.34	13.59	16.45	20.24	25.32	32.00	40.00	50.00	63.00	80.00	100.0
	CENTER FREQ., Hz										8.000	8.944	10.00	11.31	12.65	14.14	15.87	17.89	20.00	22.45	25.30	28.28
	LOWER −3 dB FREQ., Hz										6.424	7.048	7.533	7.779	7.904	7.960	7.984	8.000	8.000	8.000	8.000	8.000
	−3 dB BANDWIDTH, Hz										3.536	4.292	6.057	8.671	12.34	17.36	24.02	32.00	42.00	55.00	72.00	92 00
	NOISE BANDWIDTH, Hz										4.102	4.898	6.784	9.300	12.96	18.01	24.83	32.81	43.05	56.38	73.79	94.30
	FILTER GAIN, dB										−6.02	− 2.98	− 1.23	0.53	− 0.22	− 0.09	− 0.03	0.00	0.00	0.00	0.00	0.00
10.0	UPPER −3 dB FREQ., Hz											12.45	14.18	16.99	20.57	25.30	31.65	40.00	50.00	63 00	80.00	100.0
	CENTER FREQ., Hz											10.00	11.18	12.65	14.14	15 81	17.75	20.00	22 36	25.10	28.28	31 62
	LOWER −3 dB FREQ., Hz											8.030	8.810	9.416	9.724	9.880	9 950	9.980	10.00	10.00	10.00	10.00
	−3 dB BANDWIDTH, Hz											4.420	5.370	7.574	10.85	15.42	21.70	30 02	40.00	53.00	70.00	90.00
	NOISE BANDWIDTH, Hz											5.129	6.124	8.482	11.63	16.20	27.05	31.05	41.02	54.14	71.78	92.26
	FILTER GAIN, dB											− 6 02	− 2.98	−1.23	− 0.53	− 0 22	−0.09	− 0 03	0.00	0.00	0.00	0.00

BAND-REJECT FILTER

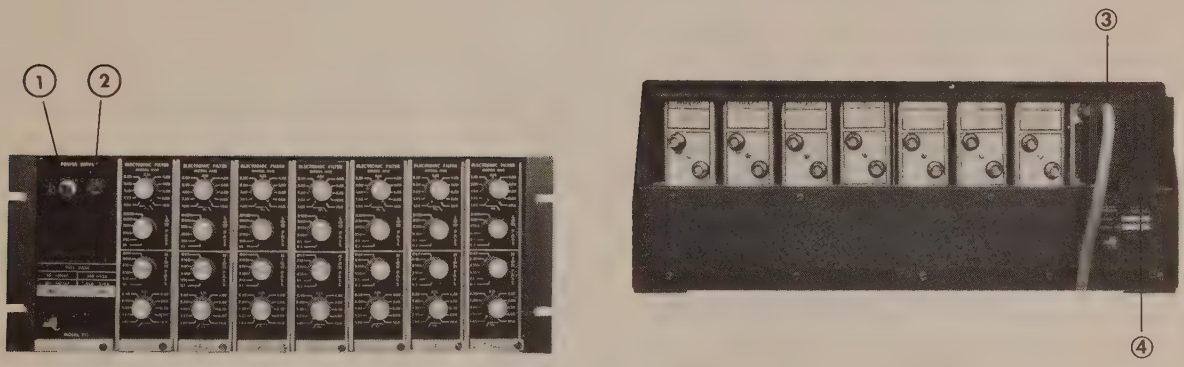
1. SET THE HIGH-PASS FILTER CUTOFF ABOVE THE LOW-PASS FILTER CUTOFF.
2. SET THE AMPLIFIER GAIN TO 0 dB.

NOTCH FREQUENCY = $\sqrt{F_{HP} \cdot F_{LP}}$
FILTER GAIN = −6 dB

UPPER −3 dB FREQUENCY = F_{HP}
LOWER −3 dB FREQUENCY = F_{LP}



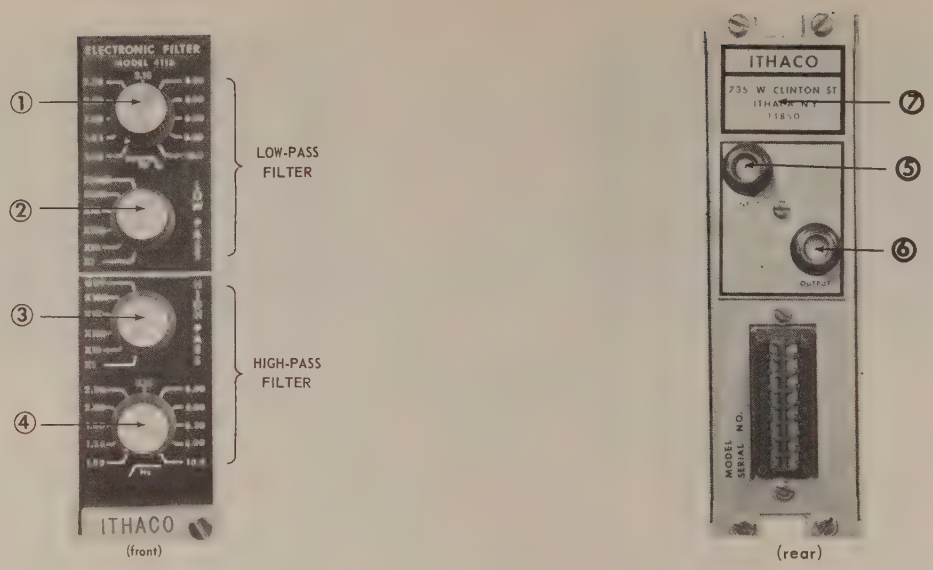
4110 SERIES FILTERS OPERATING IN MODEL S21 PORTABLE CASE



4110 SERIES FILTERS OPERATING IN MODEL S11 RACK MOUNTING CASE

①	POWER SWITCH AND LAMP	(primary power switch)
②	POWER FUSE	(3AG 1½ A SB or 3AG ¾A SB)
③	POWER CORD	(3 wire power cord for 115VAC, 60 Hz)
④	GROUND TERMINAL	The power ground and system ground are brought out on this terminal. A permanently attached clip is used to jumper the two grounds together.

FIGURE 3.1 OPERATION OF 4110 SERIES FILTERS IN MOUNTING CASES



CONTROLS AND CONNECTORS FOR MODEL 4113 VARIABLE ELECTRONIC FILTER

① FREQUENCY SETTING FOR LOW-PASS FILTER (High Frequency Cutoff)

② FREQUENCY MULTIPLIER FOR LOW-PASS FILTER (multiplies Frequency Setting)
Low-Pass Filter –3 dB Frequency, Hz = Frequency Setting X Frequency Multiplier ① X ②
Example: f –3 dB = 2.00 X 100 = 200 Hz

③ FREQUENCY MULTIPLIER FOR HIGH-PASS FILTER (multiplies Frequency Setting)

④ FREQUENCY SETTING FOR HIGH-PASS FILTER (sets High Frequency Cutoff)
High-Pass Filter –3 dB Frequency, Hz = Frequency Setting X Frequency Multiplier ④ X ③
Example: f –3 dB = 6.30 X 1K = 6.30 KHz

⑤ INPUT CONNECTOR (BNC – UG–1094/U)

⑥ OUTPUT CONNECTOR (BNC – UG–1094/U)

⑦ XLR CONNECTOR (XLR 5–31; MATING CONNECTOR XLR 5–12C) (Option 03 only)
(not shown in photo)

NOTE: Rackmount, Portable Case and Power Supply Case are always tied to power ground. The amplifier case is tied to system ground.

FIGURE 3.2 OPERATING CONTROLS AND CONNECTIONS OF 4113 FILTER

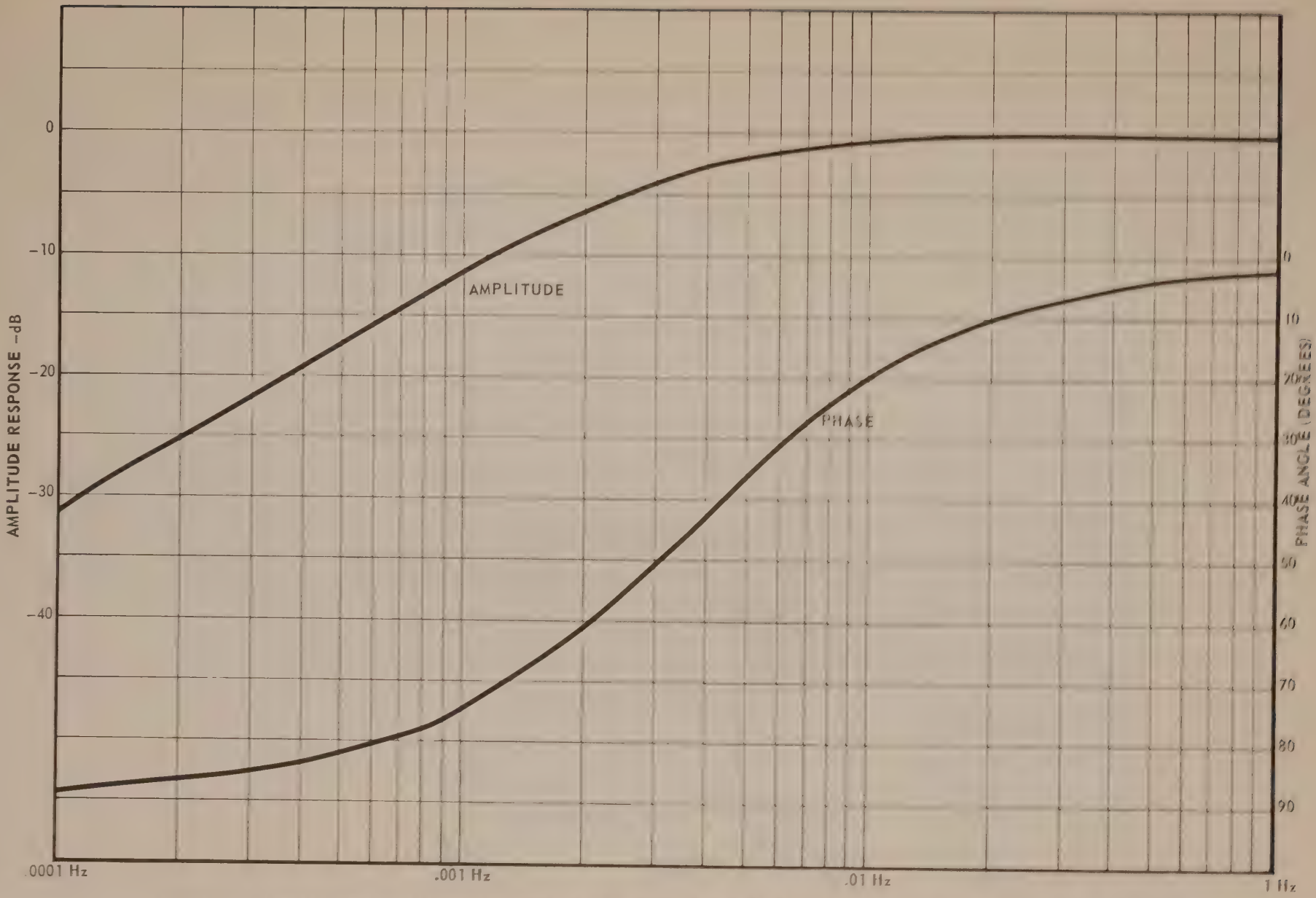


FIGURE 3.4 PHASE AND AMPLITUDE RESPONSE OF AC COUPLED INPUT OF 4110 SERIES VARIABLE ELECTRONIC FILTERS

4.0 THEORY OF OPERATION

4.1 FILTER CIRCUIT

The circuit shown in Figure 4.1 will have a low-pass response characteristic such as represented in Figure 4.3. The cutoff frequency, (where R = Xc) will be at -6 dB on the response curve. Below this cutoff frequency, the network will pass all signals with little attenuation. Above the cutoff frequency, the network attenuation will increase with frequency and the rate of attenuation will approach 12 dB/octave. The isolation amplifier prevents the RC section from loading the preceeding RC section. One objection to this network is that the response in the region of the cutoff frequency does not change as rapidly as desired.

The rate of attenuation can be improved by applying positive feedback such as illustrated in Figure 4.2. The amount of feedback will control the amount of peaking in the vicinity of the cutoff frequency. The two networks in Figure 4.1 and Figure 4.2 have similar pass-band and stop-band attenuation, but the transition region around the cutoff frequency can be controlled by positive feedback. Interchanging the RC elements in the circuit shown in Figure 4.2 to the configuration shown in Figure 4.4, the filter will change from a low-pass filter to a high-pass filter with a response as shown in Figure 4.5. When two filter sections operating as high-pass filters are cascaded. as in Figure 4.7, the overall response is a four pole high-pass filter. The feedback gain A_1 and A_2 can be set for maximal flat response. When two filter sections operating as a low-pass filter are cascaded, as in Figure 4.6, the transfer characteristic is a four pole low-pass filter. The feedback gain, A_1 and A_2, can be set for a maximal flat response. Referring to Figure 4.8, the 4110 Series Filters consist of four 2-pole sections, two sections operating as a high-pass filter and 2 sections operating as a low-pass filter. The organization of these sections is depicted in Figure 4.8.

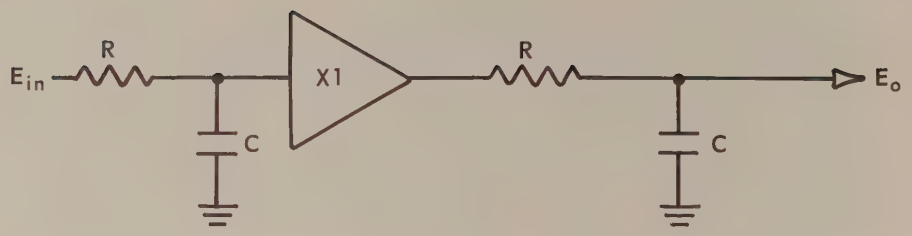


FIGURE 4.1 TWO ISOLATED RC SECTIONS OF A LOW-PASS FILTER SECTION

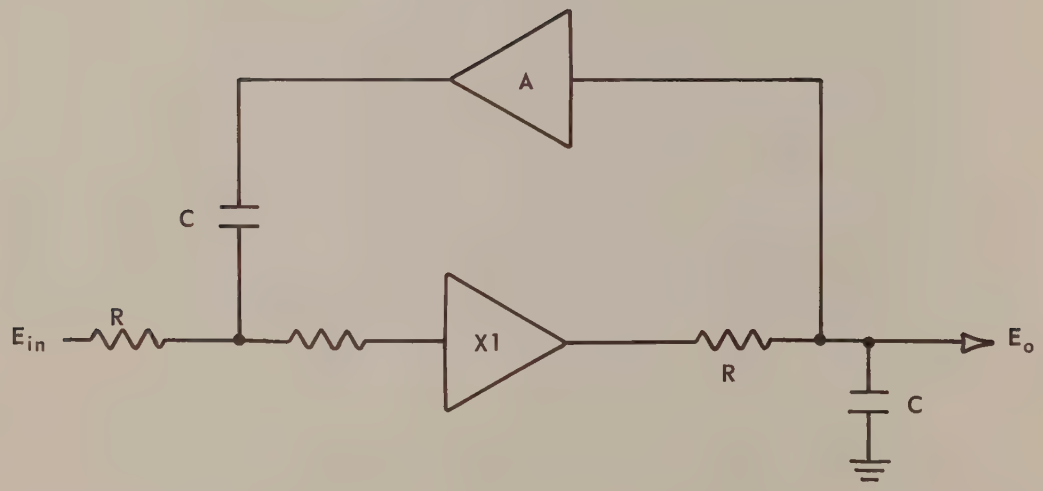


FIGURE 4.2 TWO ISOLATED RC SECTIONS OF A LOW-PASS FILTER SECTION WITH POSITIVE FEEDBACK

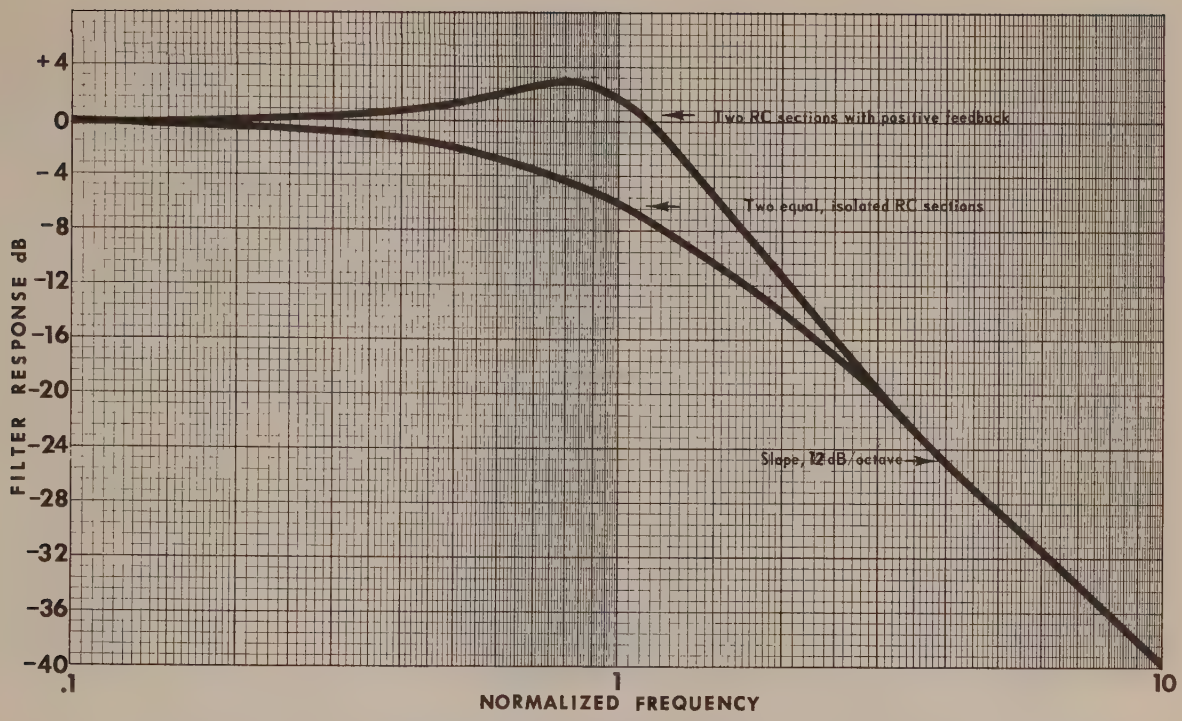


FIGURE 4.3 RESPONSE CURVE FOR TWO POLE LOW-PASS FILTER SECTION

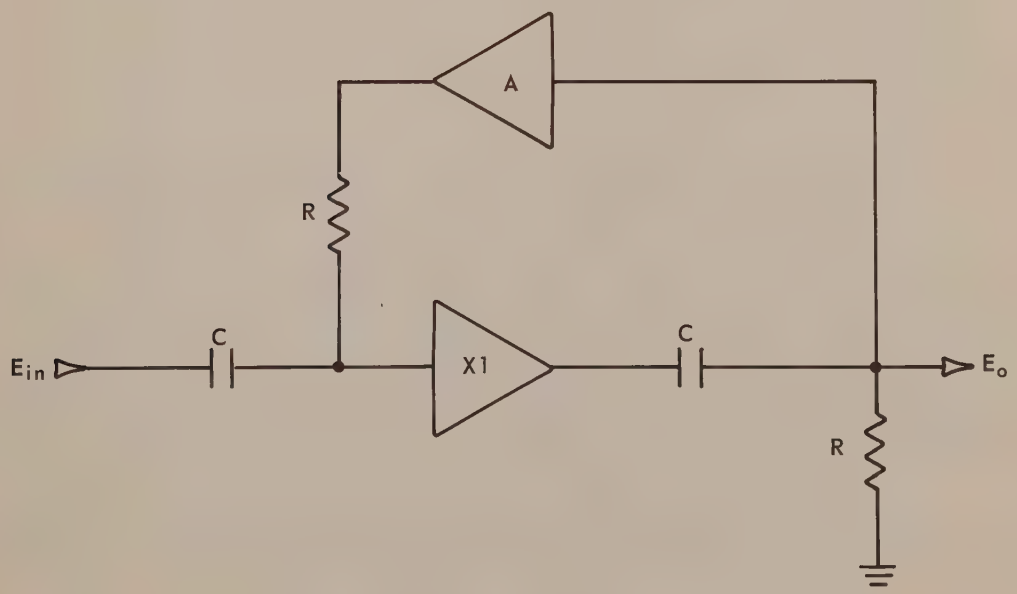


FIGURE 4.4 TWO ISOLATED RC SECTIONS OF A HIGH-PASS SECTION WITH POSITIVE FEEDBACK

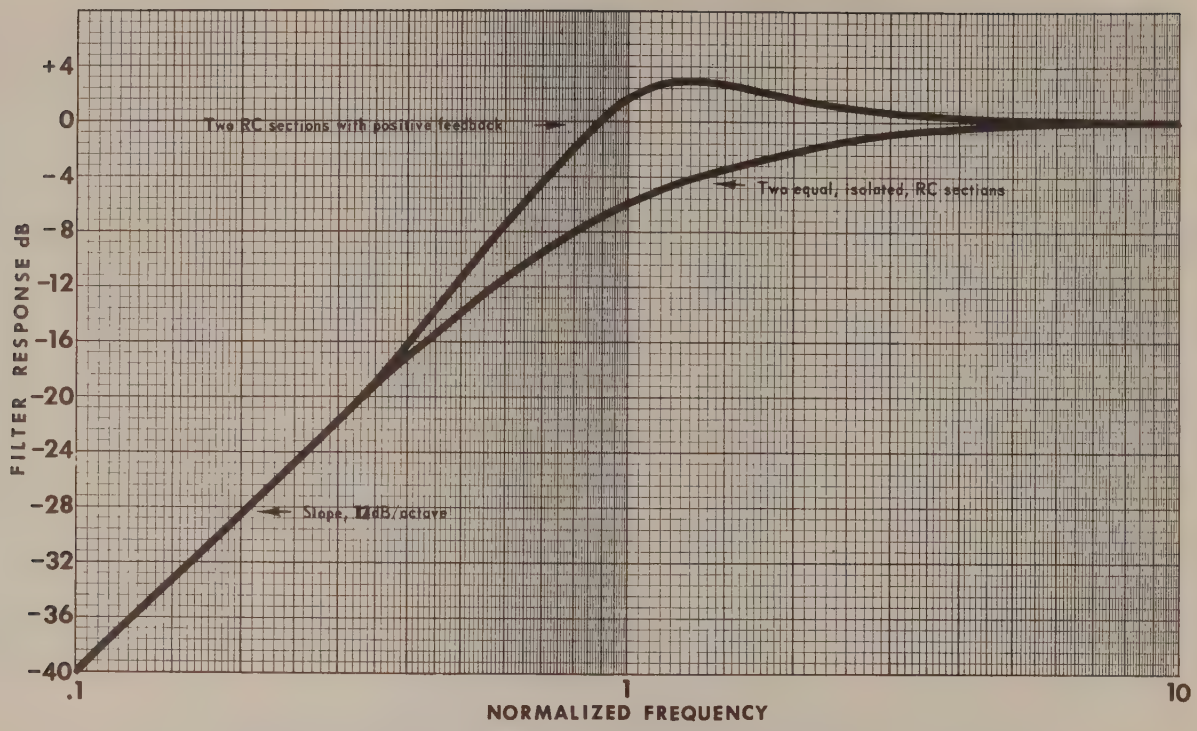


FIGURE 4.5 RESPONSE CURVE FOR TWO POLE, HIGH-PASS SECTION

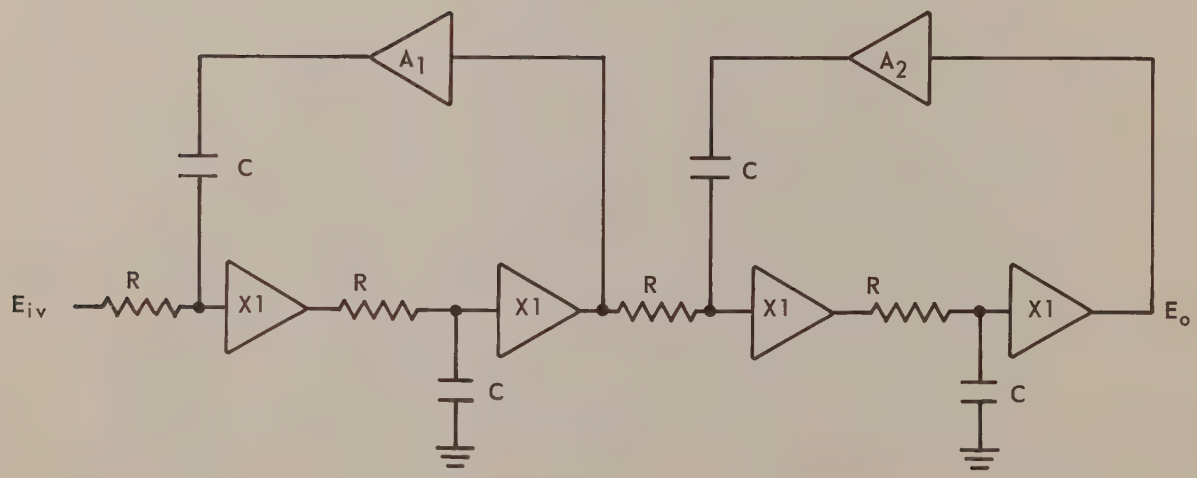


FIGURE 4.6 TWO QUADRATIC SECTIONS CASCADED TO FORM A FOUR POLE LOW-PASS FILTER

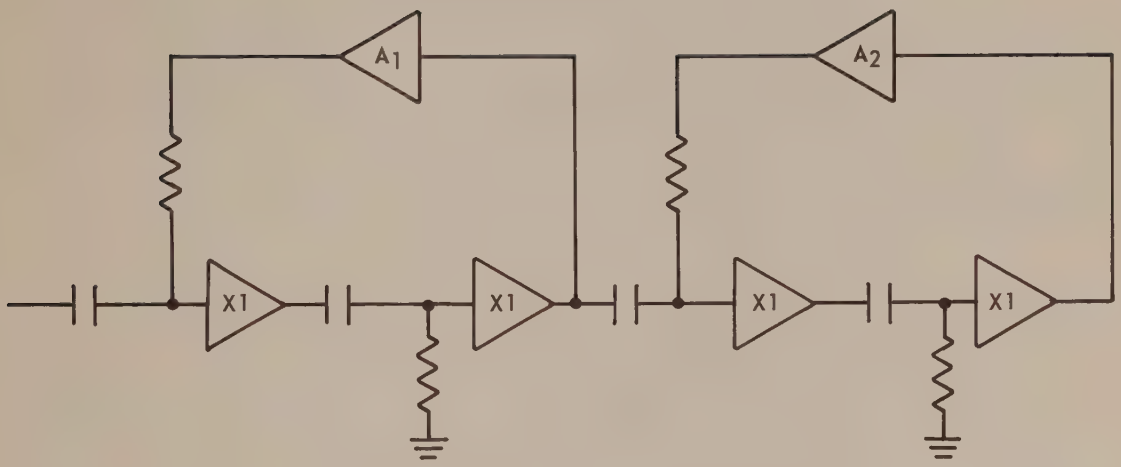


FIGURE 4.7 TWO QUADRATIC SECTIONS CASCADED TO FORM A FOUR POLE HIGH-PASS FILTER

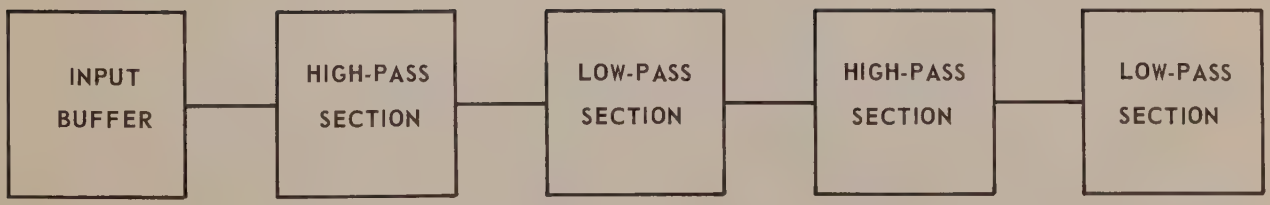
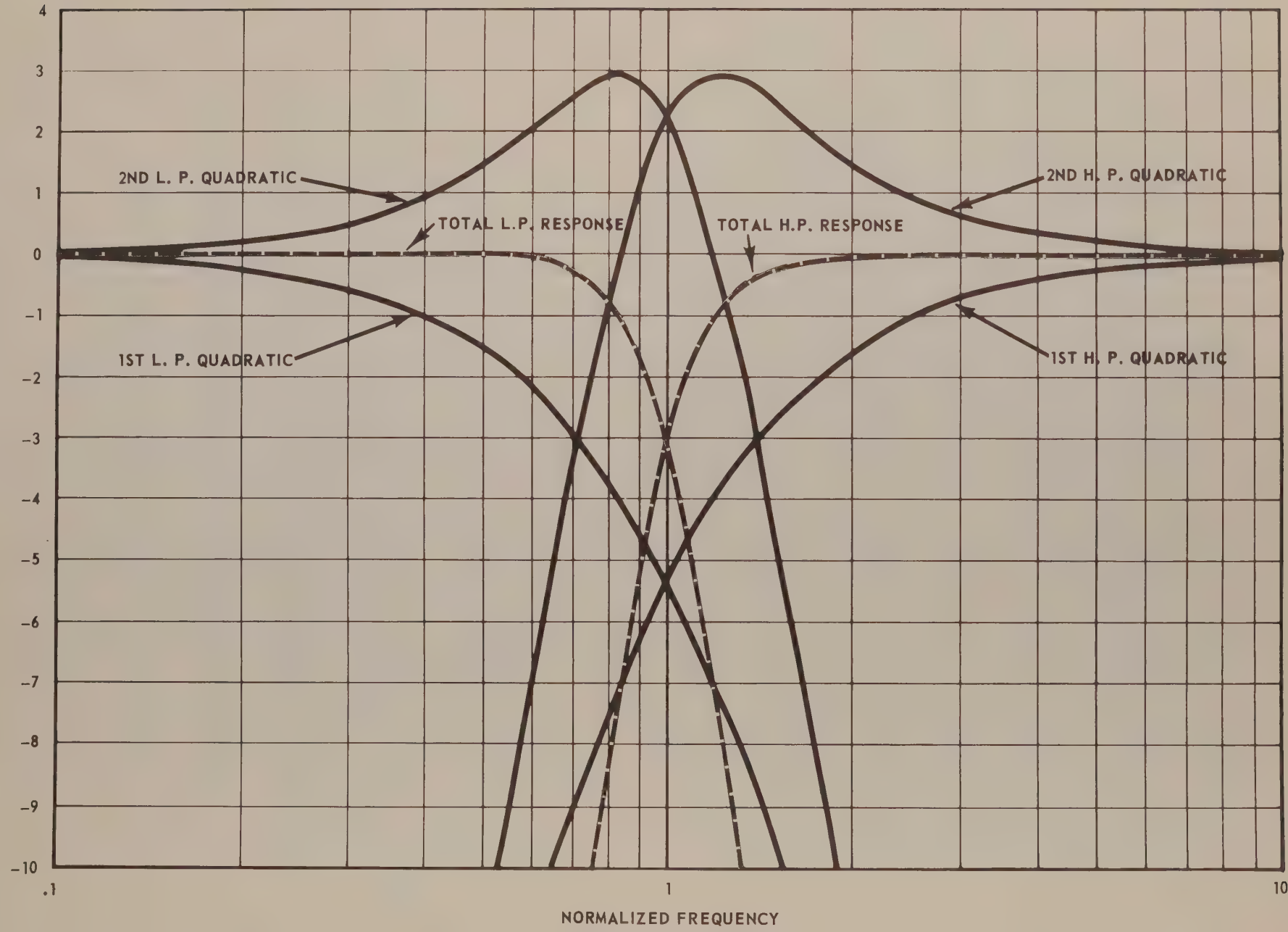


FIGURE 4.8 ORGANIZATION OF THE 4100 SERIES VARIABLE ELECTRONIC FILTER


4
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
−10
.1
1
10
2ND L. P. QUADRATIC
TOTAL L.P. RESPONSE
TOTAL H.P. RESPONSE
2ND H. P. QUADRATIC
1ST L. P. QUADRATIC
1ST H. P. QUADRATIC
NORMALIZED FREQUENCY

SECTION 5

TEST PROCEDURES

RECOMMENDED TEST EQUIPMENT

Hewlett Packard 209A Oscillator

Hewlett Packard 5326C Frequency Counter

General Radio 1450TA Attenuator

Ballantine 320A RMS Voltmeter

Tektronix Scope 531A and Type B Plug-In

Comparison Switch J49

ITHACO Model 4113 Variable Electronic Filter

ITHACO Model 451 Low Noise Amplifier

Power Supply +15V ±1% @ 150mA

-15V ±1% @ 150mA

(Any ITHACO P Series Power Supply will suffice)

HP Distortion Analyzer 331A

DC DVM 34702A

TEST No. 1 Maximum Input Level with 5,000 ohm Load (Test Set-Up No. 1)

MODEL	HIGH-PASS SECTION		LOW-PASS SECTION		FREQ	PASS-LIMIT
	Setting	Multi.	Setting	Multi.	Hz	Volts
4111	10.0	OUT	10.0	X1k	7k	7Vrms/20V p-p
4112	10.0	OUT	10.0	X10k	70k	7Vrms/20V p-p
4113	10.0	OUT	10.0	X100k	100k	7Vrms/20V p-p

Set test filter to 1 x 1 high pass, 10 x 1k low pass. Load output with 5k ohm. Apply 1kHz 7V rms sine wave to input. Measure distortion. Pass limit 0.2%.

Measured_____

TEST No. 2 Low-Pass Range Multiplier Accuracy (Test Set-Up No. 2)

*When testing the Range Multiplier Accuracy of the Models 4111 and 4112, a 2.251k ± .1% resistor is shorted across resistor A, B, C, and D on the Low-Pass Setting Switch S1 to increase the cutoff frequency so that it can be measured accurately with a counter. Tests requiring these resistors are indicated by an asterisk (*) next to the setting.

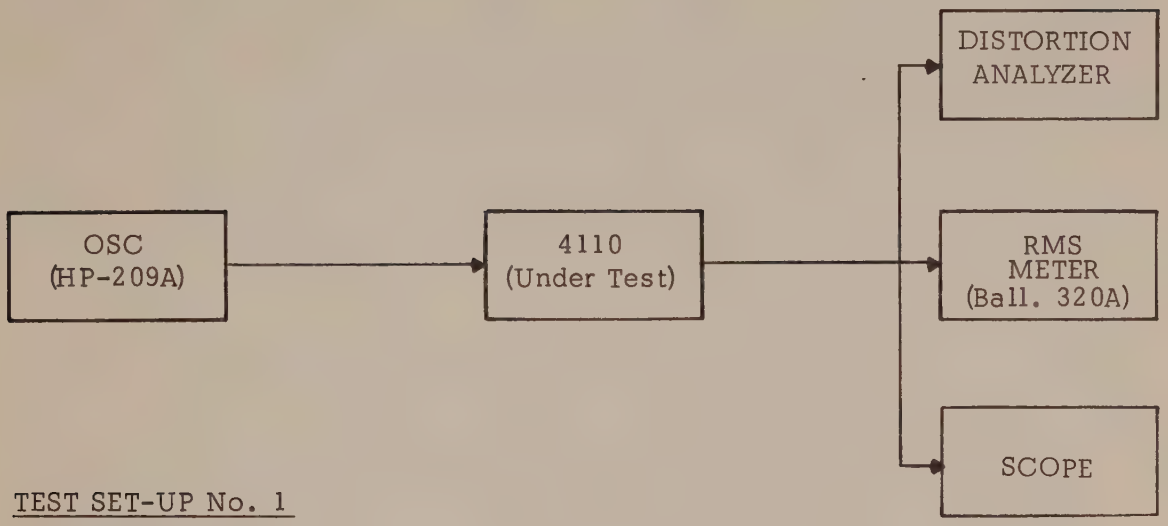
MODEL 4111

HIGH-PASS SECTION		LOW-PASS SECTION		FREQUENCY, Hz (Period, Millisec)		
Setting	Multi	Setting	Multi.	Nominal	Pass-Limit	Measured
10.0	OUT	1.0*	X .01	10	9.9-10.1(99-101)	_____
10.0	OUT	1.0*	X .1	100	99-101 (9.9-10.1)	_____
10.0	OUT	1.0*	X1	1k	990-1,010	_____
10.0	OUT	10.0	X10	100	99-101	_____
10.0	OUT	10.0	X100	1k	990-1,010	_____
10.0	OUT	1.0	X1k	1k	950-1,050	_____

MODELS 4112

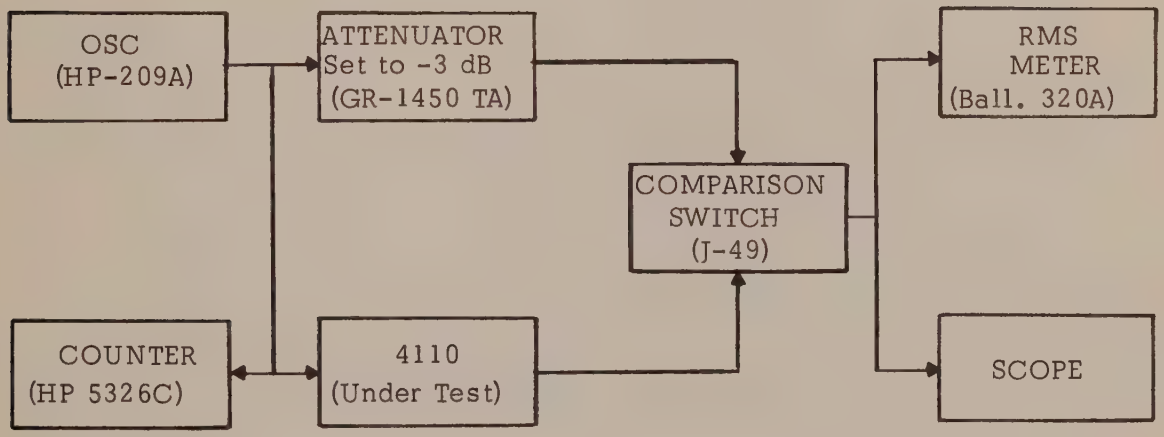
HIGH-PASS SECTION		LOW-PASS SECTION		FREQUENCY, Hz (Period, Millisec)		
Setting	Multi.	Setting	Multi.	Nominal	Pass-Limit	Measured
10.0	OUT	1.0*	X0.1	10.0	10.0-10.2(98-100)	_____
10.0	OUT	1.0*	X1	101	100-102(9.8-10.0)	_____
10.0	OUT	1.0*	X10	1.01k	1,000-1,020	_____
10.0	OUT	10.0	X100	1k	990-1,010	_____
10.0	OUT	1.0	X1k	1k	990-1,010	_____
10.0	OUT	1.0	X10k	10k	9.5k-10.5k	_____

TEST SET-UPS FOR 4110 SERIES TEST PROCEDURES



TEST SET-UP No. 1

For maximum input level



TEST SET-UP No. 2

For range multiplier accuracy and frequency setting accuracy tests.

TEST SET-UP No. 3

For broad band noise and minimum stop-band attenuation tests.

FIGURE 5.1

MODEL 4113

HIGH-PASS SECTION		LOW-PASS SECTION		FREQUENCY, Hz (Period, Millisec)		
Setting	Multi.	Setting	Multi.	Nominal	Pass-Limit	Measured
10.0	OUT	10.0	X1	10	9.90-10.1(99-101)	
10.0	OUT	10.0	X10	100	99-101(9.9-10.1)	
10.0	OUT	10.0	X100	1000	990-1,010	
10.0	OUT	1.0	X1k	1000	990-1,010	
10.0	OUT	1.0	X10k	10k	9,900-10,100	
10.0	OUT	1.0	X100k	100k	95k-105k	

TEST No. 3 High-Pass Range Multiplier Accuracy (Test Set-Up No. 2)

*When testing the range multiplier accuracy of the Model 4111 and 4112, a 2.251k ±.1% resistor is shorted across resistors A, B, C, and D on the high-pass setting switch, S3 to increase the cutoff frequency so that it can be measured accurately with a counter. Tests requiring these resistors are indicated by an asterisk (*) next to the setting.

MODELS 4111

LOW-PASS SECTION		HIGH-PASS SECTION		FREQUENCY, Hz (Period, Millisec)		
Setting	Multi.	Setting	Multi.	Nominal	Pass-Limit	Measured
10.0	X1k	1.0*	X .01	10	9.90-10.1(99-101)	
10.0	X1k	1.0*	X .1	100	99.0-101(9.9-10.1)	
10.0	X1k	1.0*	X1	1k	990-1,010	
10.0	X1k	10.0	X10	100	99.0-101	
10.0	X1k	10.0	X100	1k	990-1,010	

MODEL 4112

LOW-PASS SECTION		HIGH-PASS SECTION		FREQUENCY, Hz (Period, Millisec)		
Setting	Multi.	Section	Multi.	Nominal	Pass-Limit	Measured
10.0	X10k	1.0*	X .1	10.1	10.0-10.2(98.0-100)	
10.0	X10k	1.0*	X1	101	100-102(9.8-10.0)	
10.0	X10k	1.0*	X10	1,010	1,000-1,020	
10.0	X10k	10.0	X100	1,000	990-1,010	
10.0	X10k	1.0	X1k	1,000	990-1,010	

MODEL 4113

LOW-PASS SECTION		HIGH-PASS SECTION		FREQUENCY, Hz (Period, Millisec)		
Setting	Multi.	Setting	Multi.	Nominal	Pass-Limit	Measured
10.0	X100k	10.0	X1	10	9.90-10.1(99-101)	_____
10.0	X100k	10.0	X10	100	99-101(9.9-10.1)	_____
10.0	X100k	10.0	X100	1k	990-1,010	_____
10.0	X100k	1.0	X1k	1k	990-1,010	_____
10.0	X100k	1.0	X10k	10k	9.9k-10.1k	_____

TEST No. 4 Frequency Setting Accuracy (Test Set-Up No. 2)

NOTE: To remove the range multiplier error while check the frequency:

1. Set the oscillator frequency to 1,000 Hz ±1 Hz (100 Hz ±.1 Hz for Model 4111) and record the attenuation within ±.02 dB.

2. All subsequent readings of frequency will be taken at the same output attenuation recorded in step 1.

MODEL 4111

HIGH-PASS SECTION		LOW-PASS SECTION		FREQUENCY, Hz (Period, mS)	
Setting	Multi.	Setting	Multi.	Pass-Limit	
10.0	OUT	1.00	X100	(10.00)	Note Att._____
10.0	OUT	1.25	X100	(7.962-8.039)	
10.0	OUT	1.60	X100	(6.219-6.281)	
10.0	OUT	2.00	X100	(4.975-5.025)	
10.0	OUT	2.50	X100	(3.979-4.019)	
10.0	OUT	3.15	X100	(3.159-3.191)	
10.0	OUT	4.00	X100	(2.488-2.513)	
10.0	OUT	5.00	X100	(1.990-2.010)	
10.0	OUT	6.30	X100	(1.579-1.595)	
10.0	OUT	8.00	X100	(1.244-1.256)	
10.0	OUT	10.00	X100	(0.995-1.005)	

MODELS 4112, 4113

HIGH-PASS SECTION		LOW-PASS SECTION		FREQUENCY, Hz (Period, mS)	
Setting	Multi.	Setting	Multi.	Pass-Limit	
10.0	OUT	1.00	X1k	1,000	Note Att._____
10.0	OUT	1.25	X1k	1,244-1,256	
10.0	OUT	1.60	X1k	1,592-1,608	
10.0	OUT	2.00	X1k	1,990-2,010	
10.0	OUT	2.50	X1k	2,488-2,513	
10.0	OUT	3.15	X1k	3,134-3,166	
10.0	OUT	4.00	X1k	3,980-4,020	
10.0	OUT	5.00	X1k	4,975-5,025	
10.0	OUT	6.30	X1k	6,269-6,332	
10.0	OUT	8.00	X1k	7,960-8,040	
10.0	OUT	10.00	X1k	9,950-10,050	

MODELS 4111

LOW-PASS SECTION		HIGH-PASS SECTION		FREQUENCY, Hz (Period, mS)	
Setting	Multi.	Setting	Multi.	Pass-Limit	
10.0	X1k	1.00	X100	(10.00)	Note Att._____
10.0	X1k	1.25	X100	(7.962-8.039)	
10.0	X1k	1.60	X100	(6.219-6.281)	
10.0	X1k	2.00	X100	(4.975-5.025)	
10.0	X1k	2.50	X100	(3.979-4.019)	
10.0	X1k	3.15	X100	(3.159-3.191)	
10.0	X1k	4.00	X100	(2.488-2.513)	
10.0	X1k	5.00	X100	(1.990-2.010)	
10.0	X1k	6.30	X100	(1.579-1.595)	
10.0	X1k	8.00	X100	(1.244-1.256)	
10.0	X1k	10.00	X100	(0.995-1.005)	

LOW-PASS SECTION		HIGH-PASS SECTION		FREQUENCY, Hz (Period, mS)	
Setting	Multi.	Setting	Multi.	Pass-Limit	
10.0	X10k	1.00	X1k	1,000	Note Att._____
10.0	X10k	1.25	X1k	1,244-1,256	
10.0	X10k	1.60	X1k	1,592-1,608	
10.0	X10k	2.00	X1k	1,990-2,010	
10.0	X10k	2.50	X1k	2,488-2,513	
10.0	X10k	3.15	X1k	3,134-3,166	
10.0	X10k	4.00	X1k	3,980-4,020	
10.0	X10k	5.00	X1k	4,975-5,025	
10.0	X10k	6.30	X1k	6,269-6,332	
10.0	X10k	8.00	X1k	7,960-8,040	
10.0	X10k	10.00	X1k	9,950-10,050	

TEST No. 5 Minimum Stop-Band Attenuation (Test Set-Up No. 3)

NOTE: When testing the low-pass section, the high-pass section is set to 250 Hz to reject the line related components in the oscillator. When testing the high-pass section, the low-pass section is set to twice the test frequency to reject higher order harmonics of the test oscillator. Set external post filter for 250 Hz to 100 kHz band pass. Set post amplifier for 80 dB gain. Avoid ground loops in test setup.

Set input to 3.16V rms (+10 dB)

MODEL	HIGH-PASS SECTION		LOW-PASS SECTION		FREQ	STOP-BAND ATTENUATION, dB	
	Setting	Multi.	Setting	Multi.	Hz	Limit	Measured
4111	2.50	X100	1.00	X100	2k	(90)	
	2.50	X100	10	X100	20k	(90)	
4112	2.50	X100	10	X100	20k	(90)	
	2.50	X100	1.00	X1k	20k	(90)	
4113	2.50	X100	1.00	X1k	20k	(90)	
	2.50	X100	1.00	X10k	200k*	(90)	

Set post filter for DC-100 kHz band pass

MODEL	HIGH-PASS SECTION		LOW-PASS SECTION		FREQ	STOP-BAND ATTENUATION, dB	
	Setting	Multi.	Setting	Multi.	Hz	Limit	Measured
4111	10.0	X10	10.0	X1	5	(90)	
	10.0	X100	10.0	X10	50	(90)	
4112	10.0	X100	10.0	X10	50	(90)	
	10.0	X1k	10.0	X100	500	(90)	
4113	10.0	X1k	10.0	X100	500	(90)	
	10.0	X10k	10.0	X1k	5k	(90)	

*For this measurement only, set input signal to +6 dB (2.0V rms) and measure gain of 451 at 200 kHz separately to find its rolloff;, set 4113 post filter for 100 kHz high pass and 500 kHz low pass.

TEST No. 6 Broad-Band Noise - Shorted Input (Test Set-Up No. 3)

Operate the 451 amplifier at 60 dB gain with the low frequency rolloff set at 1 kHz. Pass limit is 50μV rms referred to the filter input.

MODEL	HIGH-PASS SECTION Setting	Multi.	LOW-PASS SECTION Setting	Multi.	BROAD-BAND NOISE Pass-Limit μV	Measured
4111	1.00	.01	10.0	X1k	(50)	
	1.00	.01	1.0	X100	(50)	
4112	1.00	.1	10.0	X10k	(50)	
	1.00	.1	1.0	X1k	(50)	
4113	1.00	1	10.0	X100k	(50)	
	1.00	1	1.0	X10k	(50)	

TEST No. 7 Filter Gain (Test Set-Up No. 2)

Set attenuator to 0 dB. Measure filter gain.

MODEL	HIGH-PASS SECTION Setting	Multi.	LOW-PASS SECTION Setting	Multi.	OSC. FREQ Hz	FILTER GAIN Pass-Limit, dB
4111	1.00	X1	10.0	X1k	1k	0 ± .1
	1.00	X10	10.0	X1k	1k	0 ± .1
	1.00	X100	10.0	X1k	1k	0 ± .1
4112	1.00	X10	10.0	X10k	10k	0 ± .1
	1.00	X100	10.0	X10k	10k	0 ± .1
	1.00	X1k	10.0	X10k	10k	0 ± .1
4113	1.00	X100	10.0	X100k	100k	0 ± .1
	1.00	X1k	10.0	X100k	100k	0 ± .1
	1.00	X10k	10.0	X100k	100k	0 ± .1

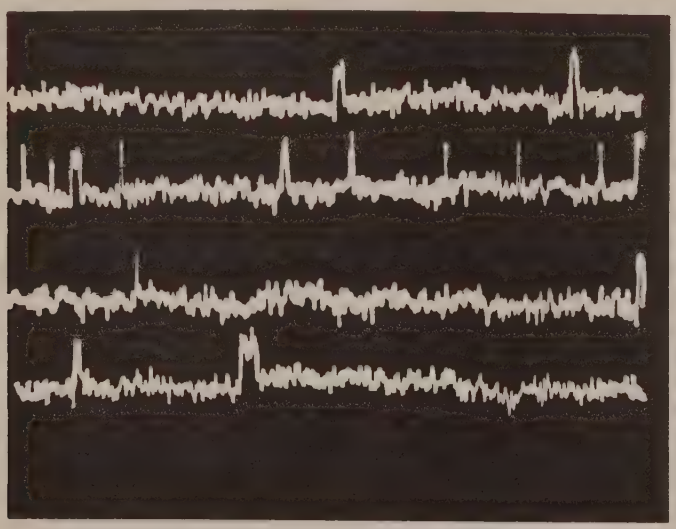
TEST No. 8 DC Offset Adjustments (Short Filter Input, Read Offset with DVM at Filter Output)

HIGH-PASS SECTION		LOW-PASS SECTION	
Setting	Multi.	Setting	Multi.
10.0	OUT	10.0	X100

Adjust output to zero ("OFFSET" on input buffer card). Now open input.
DC offset pass limit: Less than 5 mV.

TEST No. 9 Popcorn Noise (Test Set-Up No. 3)

Place shorting cap on input. Set test filter to 10 X 1k LP.
Set 4113 post filter to HP OUT 1 x 1k LP.
Set 451 post amplifier to 70 dB gain, low frequency rolloff at 1 Hz.
Replace RMS meter with scope; set to 100 mV/cm vertical sensitivity and 20 mS/cm horizontal sweep (free running).
Observe for rectangular noise pulses as shown on the waveform photo below, rejecting units exhibiting noise pulses.



6.0 REPLACEABLE PARTS

6.1 INTRODUCTION

This section contains information for ordering replacement parts. Table 6.2 lists the parts in alphabetical order of their reference designation and indicates the description and ITHACO part number for each part. When applicable, a typical manufacturer of a part is indicated.

6.2 ORDERING INFORMATION

To order a replacement part, address order or inquiry to an authorized ITHACO Representative or to:

Customer Service
ITHACO Inc.
735 West Clinton Street
Ithaca, New York 14850

Specify the following information for each part:

a) Model and complete serial number of instrument

b) ITHACO Stock Number

c) Circuit Reference Designation

d) Description

6.3 REFERENCE DESIGNATIONS

Table 6.1 is a list of reference designations.

6.4 CODE LIST OF MANUFACTURERS

Table 6.2 is a Code List of Manufacturers. The manufacturer's code is given with each part. If a code number is missing, the part is of ITHACO manufacture and can be ordered by the ITHACO part number.

REFERENCE DESIGNATIONS

A	assembly subassembly, separable or repairable
AR	amplifier
AT	attenuator pad termination
B	blower motor synchro
BT	battery
C	capacitor
CB	circuit breaker
CP	adapter, connector coupling (aperture, loop or probe) junction (coaxial or waveguide)
CR	diode rectifier
DS	alarm indicator (excluding meter)
E	antenna arrester, lightning bimetallic strip cell, aluminum or electrolytic contact core, inductor core, memory core, transformer Hall effect device insulator loop antenna magnet, permanent part, miscellaneous electrical post, binding shield, electrical terminal (individual)
F	fuse
FL	filter
G	chopper, electronic generator
H	hardware
HR	heater lamp, infrared
HS	handset
HY	network, hybrid circuit
J	connector, receptacle, electrical disconnecting device jack receptacle (connector, stationary portion)
K	relay
L	coil (all not classified as transformers) inductor
M	clock counter, electrical meter oscillograph oscilloscope recorder, elapsed time register, message strain gage thermometer timer, electric
MK	microphone
MP	frame gyroscope interlock, mechanical mechanical part mounting (not electrical circuit, not a socket) part, miscellaneous mechanical (bearing, coupling, gear, shaft) part, structural reed, vibration tuning fork
MT	transducer transducer, mode
P	connector, plug, electrical disconnecting device (connector, plug) plug, electrical (connector, movable portion)
PS	power supply
Q	transistor
R	potentiometer resistor
RT	lamp, resistance resistor, current regulating resistor, thermal thermistor
RV	resistor, voltage sensitive varistor, symmetrical
S	switch thermostat
T	transformer
TB	strip, terminal terminal board
TC	thermocouple
TP	test point
U	integrated circuit package
V	cell, light-sensitive, photo-emissive electron tube
W	cable cable assembly (with connectors) wire
WT	tiepoint, wiring
X	fuseholder lampholder socket
Y	crystal unit, piezoelectric

ABBREVIATIONS

A	ampere
AC	alternating current
ALUM	aluminum
AMPL	amplifier
ASSY	assembly
BP	bandpass
CAL	calibration
CAR	carbon
CCW	counterclockwise
CER	ceramic
CKT	circuit
COMP	composition
CRT	cathode-ray tube
CW	clockwise
dB	decibel
DC	direct current
DET	detector
DVM	digital voltmeter
ELECT	electrolytic
ENCAP	encapsulated
EXT	external
F	farads
FET	field effect transistor
FREQ	frequency
FXD	fixed
GE	germanium
GL	glass
GND	ground
H	henries
HPF	high-pass filter
HR	hour
Hz	hertz
IF	intermediate frequency
INS	insulation(ed)
INT	internal
K	kilo = 1000
LED	light emitting diode
LIN	linear taper
LOG	logarithmic taper
LPF	low-pass filter
M	Millo 10^{-3}
MEG	meg 10^{6}
METFLM	metal film
MFR	manufacturer
MINAT	miniature
MOM	momentary
MTG	mounting
MYFLM	"mylar" film
N	nano (10^{-3})
N/C	normally closed
NE	neon
N/O	normally open
NPO	negative positive zero
NSR	not separately replaceable
OSC	oscillator
OP	operational
PC	printed circuit
PF	picofarads 10^{12} farads
PIV	peak inverse volt voltage
P/P	part of
PPM	parts per million
POLY	polystyrene
POLYCARB	poly carbonate
POS	position(s)
POT	potentiometer
P-P	peak-to-peak
RC	resistor capacitor network
RECT	rectifier
REF	reference
RF	radio frequency
RMS	root-means-square
S-B	slow-blow
SCR	screw
SE	selenium
SEC	second
SECT	section(s)
SEMICON	semiconductor
SI	silicon
SIL	silver
SL	slide
SOL	solid
SPL	special
TA	tantalum
TGL	toggle
TOL	tolerance
TRIM	trimmer
μ	micro 10^{-6}
V	volt
VAR	variable
VDCW	dc working volts
VCO	voltage controlled oscillator
W/	with
W	watts
WW	wirewound
W/O	without

TABLE 6.1 LIST OF REFERENCE DESIGNATIONS AND ABBREVIATIONS

REFERENCE DESIGNATION	DESCRIPTION	PART NUMBER	MANUFACTURER CODE	MANUFACTURER PART NUMBER
A1	POWER DECOUPLING CARD ASM	C31397G1		
	CAPACITORS			
C1	15µf, 20V, 10%, Sol Ta	811501156	48	150D156X9020B2
C2	.01µf, 500V, 20%, Cer	811570019	48	5GAS-S10
C3	15µf, 20V, 10%, Sol Ta	811501156	48	150D156X9020B2
C4	.01µf, 500V, 20%, Cer	811570019	48	5GAS-Si0
	DIODES			
CR1	Rectifier	818100007		IN4005
CR2	Rectifier	818100007		IN4005
S1	RESISTOR SWITCH ASSEMBLY	C31420G1		
	RESISTORS			
R1 A,B,C,D	225.1k, 1/8W, 0.1%, Metflm	817261099	42	PME55
R2 A,B,C,D	180.1k, 1/8W, 0.1%, Metflm	817261100	42	PME55
R3 A,B,C,D	140.7k, 1/8W, 0.1%, Metflm	817261101	42	PME55
R4 A,B,C,D	112.5k, 1/8W, 0.1%, Metflm	817261102	42	PME55
R5 A,B,C,D	90.03k, 1/8W, 0.1%, Metflm	817261103	42	PME55
R6 A,B,C,D	71.45k, 1/8W, 0.1%, Metflm	817261104	42	PME55
R7 A,B,C,D	56.27k, 1/8W, 0.1%, Metflm	817261105	42	PME55
R8 A,B,C,D	45.01k, 1/8W, 0.1%, Metflm	817261106	42	PME55
R9 A,B,C,D	35.73k, 1/8W, 0.1%, Metflm	817261107	42	PME55
R10A,B,C,D	28.13k, 1/8W, 0.1%, Metflm	817201109	42	PME55
R11A,B,C,D	22.51k, 1/8W, 0.1%, Metflm	817261108	42	PME55
S2	LPF CAPACITOR SWITCH ASSEMBLY	C31399G2		
A1	CAPACITOR MODULE ASSEMBLY	B21902G2		
	CAPACITORS			
C1	5µf, 50V, 1%, Polycarb	A88104P2	31	A88104P2
C2	.5µf, 100V, 1%, Polycarb	811540041	22	W625B1B504F
C3	.05µf, 100V, 1%, Polycarb	811504043	22	W625B1B503F
C4	.005µf, 200V, 1%, Poly	811560001		

REFERENCE DESIGNATION	DESCRIPTION	ITHACO PART NUMBER	MANUFACTURER CODE	MANUFACTURER PART NUMBER
S2				
A1	CAPACITOR MODULE ASM (cont.)			
	CAPACITORS (continued)			
C7	10μF, 50V, 1%, Polycarb	811540067	22	S650DIA106F
C8	1μF, 50V, 1%, Polycarb	811540024	22	W625BIA105F
C9	.1μF, 100V, 1%, Polycarb	811540042	22	W625BIB104F
C10	.01μF, 200V, 1%, Poly	811560002	97	Style 228
A2	2ND QUADRATURE FILTER CARD	B21915G1		
AR1	Op Amp	816400018	36	LM310H
AR2	Op Amp	816400018	36	LM310H
AR3	Op Amp	816400018	36	LM310H
	CAPACITORS			
C1	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103
C2	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103
	RESISTORS			
R5	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
R6	150 ohm, 1/8W, 5%, Fxt Comp	817000026		RCR05
A3	1ST QUADRATURE FILTER CARD ASM	B21916G1		
AR1	Op Amp	816400018	36	LM310H
AR2	Op Amp	816400018	36	LM310H
AR3	Op Amp	816400018	36	LM310H

REFERENCE DESIGNATION	DESCRIPTION	ITHACO PART NUMBER	MANUFACTURER CODE	MANUFACTURER PART NUMBER
S2				
A3	1ST QUADRATURE FILTER CARD			
	CAPACITORS			
C1	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103M
C2	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103M
	RESISTORS			
R3	13.3k, 1/8W, 1%, Metflm	817212133		RN60D
R4	3.16k, 1/8W, 1%, Metflm	817211316		RN60D
R5	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
R6	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
R7	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
A4	CAPACITOR MODULE ASSEMBLY	B21902G2		
	CAPACITORS			
C1	5μF, 50V, 1%, Polycarb	A88104P2	31	A88104P2
C2	.5μF, 100V, 1%, Polycarb	811540041	22	W625B1B504F
C3	.05μF, 100V, 1%, Polycarb	811504043	22	W625B1B503F
C4	.005μF, 200V, 1%, Poly	811560001	97	Style 228
C7	10μF, 50V, 1%, Polycarb	811540067	22	S650DIA106F
C8	1μF, 50V, 1%, Polycarb	811540024	22	W625B1A105F
C9	.1μF, 100V, 1%, Polycarb	811540042	22	W625B1B104F
C10	.01μF, 200V, 1%, Poly	811560002	97	Style 228

REFERENCE DESIGNATION	DESCRIPTION	ITHACO PART NUMBER	MANUFACTURER CODE	MANUFACTURER PART NUMBER
S3	HPF CAPACITOR SWITCH ASSEMBLY	C31460G2		
A1	CAPACITOR MODEULE ASSEMBLY	B21902G2		
	CAPACITORS			
C1	5μF, 50V, 1%, Polycarb	A88104P2	31	A88104P2
C2	.5μF, 100V, 1%, Polycarb	811540041	22	W625B1B504F
C3	.05μF, 100V, 1%, Polycarb	811540043	22	W625B1B503F
C4	.005μF, 200V, 1%, Poly	811560001	97	Style 228
C7	10μF, 50V, 1%, Polycarb	811540067	22	S650DIA106F
C8	1μF, 50V, 1%, Polycarb	811540024	22	W625B1A105F
C9	.1μF, 100V, 1%, Polycarb	811540042	22	W625B1B104F
C10	.01μF, 200V, 1%, Poly	811560002	97	Style 228
A2	2ND QUADRATURE FILTER CARD	B21915G1		
AR1	Op Amp	816400018	36	LM310H
AR2	Op Amp	816400018	36	LM310H
AR3	Op Amp	816400018	36	LM310H
	CAPACITORS			
C1	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103
C2	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103
	RESISTORS			
R5	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
R6	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
A3	1ST QUADRATURE FILTER CARD ASM	B21916G1		
AR1	Op Amp	816400018	36	LM310H
AR2	Op Amp	816400018	36	LM310H
AR3	Op Amp	816400018	36	LM310H

REFERENCE DESIGNATION	DESCRIPTION	ITHACO PART NUMBER	MANUFACTURER CODE	MANUFACTURER PART NUMBER
S3				
A3	1ST QUADRATURE FILTER CARD ASM	B21916G1		
	CAPACITORS			
C1	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103M
C2	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103M
	RESISTORS			
R3	13.3k, 1/8W, 1%, Metflm	817212133		RN60D
R4	3.16K, 1/8W, 1%, Metflm	817211316		RN60D
R5	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
R6	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
R7	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
A4	CAPACITOR MODULE ASSEMBLY	B21902G2		
	CAPACITORS			
C1	5μF, 50V, 1%, Polycarb	A88104P2	31	A88104P2
C2	.5μF, 100V, 1%, Polycarb	811540041	22	W625B1B504F
C3	.05μF, 100V, 1%, Polycarb	811540043	22	W625B1B503F
C4	.005μF, 200V, 1%, Poly	811560001	97	Style 228
C7	10μF, 50V, 1%, Polycarb	811540067	22	S650DIA106F
C8	1μF, 50V, 1%, Polycarb	811540024	22	W625B1A105F
C9	.1μF, 100V, 1%, Polycarb	811540042	22	W625B1B104F
C10	.01μF, 200V, 1%, Poly	811500002	97	Style 228

REFERENCE DESIGNATION	DESCRIPTION	PART NUMBER	MANUFACTURER CODE	MANUFACTURER PART NUMBER
S3				
A5	INPUT BUFFER CARD ASSEMBLY	B21903G1		
AR1	Op Amp	816400018	36	LM310H
	CAPACITORS			
C1	2μf, 200V, 10%, Myflm	811553013	22	W230B1C-205K
C2	220pf, 1000V, 20%, Cer	811572013	48	10TS-T22
C3	.01μf, 500V, 20%, Cer	811570019	48	5GAS-S10
C4	.01μf, 500V, 20%, Cer	811570019	48	5GAS-S10
	DIODES			
CR1	S I IN4148	818100003		IN4148
CR2	Low Leakage	A86003P1	31	A86003P1
CR3	Low Leakage	A86003P1	31	A86003P1
	TRANSISTORS			
Q1	PNP	818203906		2N3906
Q2	NPN	818203904		2N3904
Q3	Dual N-Chan Fet	A86021P1	31	A86021P1
	RESISTORS			
R1	330 ohm, 1/4W, 5%, Fxd Comp	817007331		RC07
R2	22M, 1/4W, 5%, Fxd Comp	817007226		RC07
R3	825 ohm, 1/4W, 5%, Fxd Comp	817007825		RC07
R4	909 ohm, 1/8W, 1%, Metflm	817210909		RN60D
R5	22 ohm, 1/4W, 5%, Fxd Comp	817007220		RC07
R6	7.5k, 1/8W, 1%, Metflm	817211750		RN60D
R7	51.1 ohm, 1/8W, 1%, Metflm	817219511		RN60D
R8	402 ohm, 1/8W, 1%, Metflm	817210402		RN60D
R9	511 ohm, 1/8W, 1%, Metflm	817210511		RN60D
R10	75 ohm, 1/8W, 1%, Metflm	817219750		RN60D
R11	7.5k, 1/8W, 1%, Metflm	817211750		RN60D
R12	10k, 1/8W, 1%, Metflm	817212100		RN60D
R13	Var, 200 ohm, 10%	817801043	29	66XR200
R14	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05

REFERENCE DESIGNATION	DESCRIPTION	PART NUMBER	MANUFACTURER CODE	MANUFACTURER PART NUMBER
S4	RESISTOR SWITCH ASSEMBLY	C31420G1		
	RESISTORS			
R1 A,B,C,D	225.1k, 1/8W, 0.1%, Metflm	817261099	42	PME55
R2 A,B,C,D	180.1k, 1/8W, 0.1%, Metflm	817261100	42	PME55
R3 A,B,C,D	140.7k, 1/8W, 0.1%, Metflm	817261101	42	PME55
R4 A,B,C,D	112.5k, 1/8W, 0.1%, Metflm	817261102	42	PME55
R5 A,B,C,D	90.03k, 1/8W, 0.1%, Metflm	817261103	42	PME55
R6 A,B,C,D	71.45k, 1/8W, 0.1%, Metflm	817261104	42	PME55
R7 A,B,C,D	56.27k, 1/8W, 0.1%, Metflm	817261105	42	PME55
R8 A,B,C,D	45.01k, 1/8W, 0.1%, Metflm	817261106	42	PME55
R9 A,B,C,D	35.73k, 1/8W, 0.1%, Metflm	817261107	42	PME55
R10 A,B,C,D	28.13k, 1/8W, 0.1%, Metflm	817261109	42	PME55
R11 A,B,C,D	22.51k, 1/8W, 0.1%, Metflm	817261108	42	PME55
J1	Connector, BNC	812130110	19	30355-1
J2	Connector, BNC	812130110	19	30355-1
L1	Ferrite Bead	811800014	51	1568
L2	Ferrite Bead	811800014	51	1568
P1	Connector, 16 Pin	812122003	4	26-4100-16P

REFERENCE DESIGNATION	DESCRIPTION	PART NUMBER	MANUFACTURER CODE	MANUFACTURER PART NUMBER
A1	POWER DECOUPLING CARD ASM	C31397G1		
	CAPACITORS			
C1	15µf, 20V, 10%, Sol Ta	811501156	48	150D156X9020B2
C2	.01µf, 500V, 20%, Cer	811570019	48	5GAS-S10
C3	15µf, 20V, 10%, Sol Ta	811501156	48	150D156X9020B2
C4	.01µf, 500V, 20%, Cer	811570019	48	5GAS-S10
	DIODES			
CR1	Rectifier	818100007		IN4005
CR2	Rectifier	818100007		IN4005
S1	RESISTOR SWITCH ASSEMBLY	C31420G2		
	RESISTORS			
R1 A,B,C,D	225.1k, 1/8W, 0.1%, Metflm	817261099	42	PME55
R2 A,B,C,D	180.1k, 1/8W, 0.1%, Metflm	817261100	42	PME55
R3 A,B,C,D	140.7k, 1/8W, 0.1%, Metflm	817261101	42	PME55
R4 A,B,C,D	112.5k, 1/8W, 0.1%, Metflm	817261102	42	PME55
R5 A,B,C,D	90.03k, 1/8W, 0.1%, Metflm	817261103	42	PME55
R6 A,B,C,D	71.45k, 1/8W, 0.1%, Metflm	817261104	42	PME55
R7 A,B,C,D	56.27k, 1/8W, 0.1%, Metflm	817261105	42	PME55
R8 A,B,C,D	45.01k, 1/8W, 0.1%, Metflm	817261106	42	PME55
R9 A,B,C,D	35.73k, 1/8W, 0.1%, Metflm	817261107	42	PME55
R10 A,B,C,D	28.13k, 1/8W, 0.1%, Metflm	817201109	42	PME55
R11 A,B,C,D	22.51k, 1/8W, 0.1%, Metflm	817261108	42	PME55
S2	LPF CAPACITOR SWITCH ASSEMBLY	C31399G2		
A1	CAPACITOR MODULE ASSEMBLY	B21902G2		
	CAPACITORS			
C1	5µf, 50V, 1%, Polycarb	A88104P2	31	A88104P2
C2	.5µf, 100V, 1%, Polycarb	811540041	22	W625B1B504F
C3	.05µf, 100V, 1%, Polycarb	811504043	22	W625B1B503F
C4	.005µf, 200V, 1%, Poly	811560001		

REFERENCE DESIGNATION	DESCRIPTION	ITHACO PART NUMBER	MANUFACTURER CODE	MANUFACTURER PART NUMBER
S2				
A1	CAPACITOR MODULE ASM (cont.)			
	CAPACITORS (continued)			
C7	10μF, 50V, 1%, Polycarb	811540067	22	S650DIA106F
C8	1μF, 50V, 1%, Polycarb	811540024	22	W625BIA105F
C9	.1μF, 100V, 1%, Polycarb	811540042	22	W625BIB104F
C10	.01μF, 200V, 1%, Poly	811560002	97	Style 228
A2	2ND QUADRATURE FILTER CARD	B21915G1		
AR1	Op Amp	816400018	36	LM310H
AR2	Op Amp	816400018	36	LM310H
AR3	Op Amp	816400018	36	LM310H
	CAPACITORS			
C1	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103M
C2	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103M
	RESISTORS			
R5	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
R6	150 ohm, 1/8W, 5%, Fxt Comp	817000026		RCR05
A3	1ST QUADRATURE FILTER CARD ASM	B21916G1		
AR1	Op Amp	816400018	36	LM310H
AR2	Op Amp	816400018	36	LM310H
AR3	Op Amp	816400018	36	LM310H

REFERENCE DESIGNATION	DESCRIPTION	ITHACO PART NUMBER	MANUFACTURER CODE	MANUFACTURER PART NUMBER
S2				
A3	1ST QUADRATURE FILTER CARD			
	CAPACITORS			
C1	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103M
C2	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103M
	RESISTORS			
R3	13.3k, 1/8W, 1%, Metflm	817212133		RN60D
R4	3.16k, 1/8W, 1%, Metflm	817211316		RN60D
R5	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
R6	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
R7	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
A4	CAPACITOR MODULE ASSEMBLY	B21902G2		
	CAPACITORS			
C1	5μF, 50V, 1%, Polycarb	A88104P2	31	A88104P2
C2	.5μF, 100V, 1%, Polycarb	811540041	22	W625B1B504F
C3	.05μF, 100V, 1%, Polycarb	811504043	22	W625B1B503F
C4	.005μF, 200V, 1%, Poly	811560001	97	Style 228
C7	10μF, 50V, 1%, Polycarb	811540067	22	S650DA106F
C8	1μF, 50V, 1%, Polycarb	811540024	22	W625B1A105F
C9	.1μF, 100V, 1%, Polycarb	811540042	22	W625B1B104F
C10	.01μF, 200V, 1%, Poly	811560002	97	Style 228

REFERENCE DESIGNATION	DESCRIPTION	ITHACO PART NUMBER	MANUFACTURER CODE	MANUFACTURER PART NUMBER
S3	HPF CAPACITOR SWITCH ASSEMBLY	C31460G2		
A1	CAPACITOR MODEULE ASSEMBLY	B21902G2		
	CAPACITORS			
C1	5μF, 50V, 1%, Polycarb	A88104P2	31	A88104P2
C2	.5μF, 100V, 1%, Polycarb	811540041	22	W625B1B504F
C3	.05μF, 100V, 1%, Polycarb	811540043	22	W625B1B503F
C4	.005μF, 200V, 1%, Poly	811560001	97	Style 228
C7	10μF, 50V, 1%, Polycarb	811540067	22	S650DIA106F
C8	1μF, 50V, 1%, Polycarb	811540024	22	W625B1A105F
C9	.1μF, 100V, 1%, Polycarb	811540042	22	W625B1B104F
C10	.01μF, 200V, 1%, Poly	811560002	97	Style 228
A2	2ND QUADRATURE FILTER CARD	B21915G1		
AR1	Op Amp	816400018	36	LM310H
AR2	Op Amp	816400018	36	LM310H
AR3	Op Amp	816400018	36	LM310H
	CAPACITORS			
C1	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103M
C2	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103M
	RESISTORS			
R5	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
R6	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
A3	1ST QUADRATURE FILTER CARD ASM	B21916G1		
AR1	Op Amp	816400018	36	LM310H
AR2	Op Amp	816400018	36	LM310H
AR3	Op Amp	816400018	36	LM310H

REFERENCE DESIGNATION	DESCRIPTION	ITHACO PART NUMBER	MANUFACTURER CODE	MANUFACTURER PART NUMBER
S3				
A3	1ST QUADRATURE FILTER CARD ASM	B21916G1		
	CAPACITORS			
C1	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103M
C2	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103M
	RESISTORS			
R3	13.3k, 1/8W, 1%, Metflm	817212133		RN60D
R4	3.16K, 1/8W, 1%, Metflm	817211316		RN60D
R5	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
R6	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
R7	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
A4	CAPACITOR MODULE ASSEMBLY	B21902G2		
	CAPACITORS			
C1	5μF, 50V, 1%, Polycarb	A88104P2	31	A88104P2
C2	.5μF, 100V, 1%, Polycarb	811540041	22	W625B1B504F
C3	.05μF, 100V, 1%, Polycarb	811540043	22	W625B1B503F
C4	.005μF, 200V, 1%, Poly	811560001	97	Style 228
C7	10μF, 50V, 1%, Polycarb	811540067	22	S650DIA106F
C8	1μF, 50V, 1%, Polycarb	811540024	22	W625B1A105F
C9	.1μF, 100V, 1%, Polycarb	811540042	22	W625B1B104F
C10	.01μF, 200V, 1%, Poly	811500002	97	Style 228

REFERENCE DESIGNATION	DESCRIPTION	PART NUMBER	MANUFACTURER CODE	MANUFACTURER PART NUMBER
S3				
A5	INPUT BUFFER CARD ASSEMBLY	B21903G1		
AR1	Op Amp	816400018	36	LM310H
	CAPACITORS			
C1	2μf, 200V, 10%, Myflm	811553013	22	W230B1C-205K
C2	220pf, 1000V, 20%, Cer	811572013	48	10TS-T22
C3	.01μf, 500V, 20%, Cer	811570019	48	5GAS-S10
C4	.01μf, 500V, 20%, Cer	811570019	48	5GAS-S10
	DIODES			
CR1	S I IN4148	818100003		IN4148
CR2	Low Leakage	A86003P1	31	A86003P1
CR3	Low Leakage	A86003P1	31	A86003P1
	TRANSISTORS			
Q1	PNP	818203906		2N3906
Q2	NPN	818203904		2N3904
Q3	Dual N-Chan Fet	A86021P1	31	A86021P1
	RESISTORS			
R1	330 ohm, 1/4W, 5%, Fxd Comp	817007331		RC07
R2	22M, 1/4W, 5%, Fxd Comp	817007226		RC07
R3	825 ohm, 1/4W, 5%, Fxd Comp	817007825		RC07
R4	909 ohm, 1/8W, 1%, Metflm	817210909		RN60D
R5	22 ohm, 1/4W, 5%, Fxd Comp	817007220		RC07
R6	7.5k, 1/8W, 1%, Metflm	817211750		RN60D
R7	51.1 ohm, 1/8W, 1%, Metflm	817219511		RN60D
R8	402 ohm, 1/8W, 1%, Metflm	817210402		RN60D
R9	511 ohm, 1/8W, 1%, Metflm	817210511		RN60D
R10	75 ohm, 1/8W, 1%, Metflm	817219750		RN60D
R11	7.5k, 1/8W, 1%, Metflm	817211750		RN60D
R12	10k, 1/8W, 1%, Metflm	817212100		RN60D
R13	Var, 200 ohm, 10%	817801043	29	66XR200
R14	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05

REFERENCE DESIGNATION	DESCRIPTION	PART NUMBER	MANUFACTURER CODE	MANUFACTURER PART NUMBER
S4	RESISTOR SWITCH ASSEMBLY	C31420G2	31	
	RESISTORS			
R1 A,B,C,D	225.1k, 1/8W, 0.1%, Metflm	817261099	42	PME55
R2 A,B,C,D	180.1k, 1/8W, 0.1%, Metflm	817261100	42	PME55
R3 A,B,C,D	140.7k, 1/8W, 0.1%, Metflm	817261101	42	PME55
R4 A,B,C,D	112.5k, 1/8W, 0.1%, Metflm	817261102	42	PME55
R5 A,B,C,D	90.03k, 1/8W, 0.1%, Metflm	817261103	42	PME55
R6 A,B,C,D	71.45k, 1/8W, 0.1%, Metflm	817261104	42	PME55
R7 A,B,C,D	56.27k, 1/8W, 0.1%, Metflm	817261105	42	PME55
R8 A,B,C,D	45.01k, 1/8W, 0.1%, Metflm	817261106	42	PME55
R9 A,B,C,D	35.73k, 1/8W, 0.1%, Metflm	817261107	42	PME55
R10 A,B,C,D	28.13k, 1/8W, 0.1%, Metflm	817261109	42	PME55
R11 A,B,C,D	22.51k, 1/8W, 0.1%, Metflm	817261108	42	PME55
J1	Connector, BNC	812130110	19	30355-1
J2	Connector, BNC	812130110	19	30355-1
L1	Ferrite Bead	811800014	51	1568
L2	Ferrite Bead	811800014	51	1568
P1	Connector, 16 Pin	812122003	4	26-4100-16P

REFERENCE DESIGNATION	DESCRIPTION	PART NUMBER	MANUFACTURER CODE	MANUFACTURER PART NUMBER
A1	POWER DECOUPLING CARD ASM	C31397G1		
	CAPACITORS			
C1	15µf, 20V, 10%, Sol Ta	811501156	48	150D156X9020B2
C2	.01µf, 500V, 20%, Cer	811570019	48	5GAS-S10
C3	15µf, 20V, 10%, Sol Ta	811501156	48	150D156X9020B2
C4	.01µf, 500V, 20%, Cer	811570019	48	5GAS-S10
	DIODES			
CR1	Rectifier	818100007		IN4005
CR2	Rectifier	818100007		IN4005
S1	RESISTOR SWITCH ASSEMBLY	C31420G3		
	RESISTORS			
R1 A,B,C,D	22.51k, 1/8W, 0.1%, Metflm	817261108	42	PME55
R2 A,B,C,D	18.01k, 1/8W, 0.1%, Metflm	817261110	42	PME55
R3 A,B,C,D	14.07k, 1/8W, 0.1%, Metflm	817261112	42	PME55
R4 A,B,C,D	11.25k, 1/8W, 0.1%, Metflm	817261113	42	PME55
R5 A,B,C,D	9.003k, 1/8W, 0.1%, Metflm	817261114	42	PME55
R6 A,B,C,D	7.145k, 1/8W, 0.1%, Metflm	817261115	42	PME55
R7 A,B,C,D	5.627k, 1/8W, 0.1%, Metflm	817261116	42	PME55
R8 A,B,C,D	4.501k, 1/8W, 0.1%, Metflm	817261117	42	PME55
R9 A,B,C,D	3.573k, 1/8W, 0.1%, Metflm	817261118	42	PME55
R10 A,B,C,D	2.813k, 1/8W, 0.1%, Metflm	817261119	42	PME55
R11 A,B,C,D	2.251k, 1/8W, 0.1%, Metflm	817261120	42	PME55
S2	LPF CAPACITOR SWITCH ASSEMBLY	C31399G2		
A1	CAPACITOR MODULE ASSEMBLY	B21902G 2		
	CAPACITORS			
C1	5µf, 50V, 1%, Polycarb	A88104P2	31	A88104P2
C2	.5µf, 100V, 1%, Polycarb	811540041	22	W625B1B504F
C3	.05µf, 100V, 1%, Polycarb	811504043	22	W625B1B503F
C4	.005µf, 200V, 1%, Poly	811560001		

REFERENCE DESIGNATION	DESCRIPTION	ITHACO PART NUMBER	MANUFACTURER CODE	MANUFACTURER PART NUMBER
S2				
A1	CAPACITOR MODULE ASM (cont.)			
	CAPACITORS (continued)			
C7	10μF, 50V, 1%, Polycarb	811540067	22	S650DIA106F
C8	1μF, 50V, 1%, Polycarb	811540024	22	W625BIA105F
C9	.1μF, 100V, 1%, Polycarb	811540042	22	W625BIB104F
C10	.01μF, 200V, 1%, Poly	811560002	97	Style 228
A2	2ND QUADRATURE FILTER CARD	B21915G1		
AR1	Op Amp	816400018	36	LM310H
AR2	Op Amp	816400018	36	LM310H
AR3	Op Amp	816400018	36	LM310H
	CAPACITORS			
C1	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103M
C2	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103M
	RESISTORS			
R5	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
R6	150 ohm, 1/8W, 5%, Fxt Comp	817000026		RCR05
A3	1ST QUADRATURE FILTER CARD ASM	B21916G1		
AR1	Op Amp	816400018	36	LM310H
AR2	Op Amp	816400018	36	LM310H
AR3	Op Amp	816400018	36	LM310H

REFERENCE DESIGNATION	DESCRIPTION	ITHACO PART NUMBER	MANUFACTURER CODE	MANUFACTURER PART NUMBER
S2				
A3	1ST QUADRATURE FILTER CARD			
	CAPACITORS			
C1	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103M
C2	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103M
	RESISTORS			
R3	13.3k, 1/8W, 1%, Metflm	817212133		RN60D
R4	3.16k, 1/8W, 1%, Metflm	817211316		RN60D
R5	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
R6	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
R7	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
A4	CAPACITOR MODULE ASSEMBLY	B21902G2		
	CAPACITORS			
C1	5μF, 50V, 1%, Polycarb	A88104P2	31	A88104P2
C2	.5μF, 100V, 1%, Polycarb	811540041	22	W625B1B504F
C3	.05μF, 100V, 1%, Polycarb	811504043	22	W625B1B503F
C4	.005μF, 200V, 1%, Poly	811560001	97	Style 228
C7	10μF, 50V, 1%, Polycarb	811540067	22	S650DIA106F
C8	1μF, 50V, 1%, Polycarb	811540024	22	W625B1A105F
C9	.1μF, 100V, 1%, Polycarb	811540042	22	W625B1B104F
C10	.01μF, 200V, 1%, Poly	811560002	97	Style 228

REFERENCE DESIGNATION	DESCRIPTION	ITHACO PART NUMBER	MANUFACTURER CODE	MANUFACTURER PART NUMBER
S3	HPF CAPACITOR SWITCH ASSEMBLY	C31460G2		
A1	CAPACITOR MODEULE ASSEMBLY	B21902G2		
	CAPACITORS			
C1	5μF, 50V, 1%, Polycarb	A88104P2	31	A88104P2
C2	.5μF, 100V, 1%, Polycarb	811540041	22	W625B1B504F
C3	.05μF, 100V, 1%, Polycarb	811540043	22	W625B1B503F
C4	.005μF, 200V, 1%, Poly	811560001	97	Style 228
C7	10μF, 50V, 1%, Polycarb	811540067	22	S650D1A106F
C8	1μF, 50V, 1%, Polycarb	811540024	22	W625B1A105F
C9	.1μF, 100V, 1%, Polycarb	811540042	22	W625B1B104F
C10	.01μF, 200V, 1%, Poly	811560002	97	Style 228
A2	2ND QUADRATURE FILTER CARD	B21915G1		
AR1	Op Amp	816400018	36	LM310H
AR2	Op Amp	816400018	36	LM310H
AR3	Op Amp	816400018	36	LM310H
	CAPACITORS			
C1	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103M
C2	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103M
	RESISTORS			
R5	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
R6	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
A3	1ST QUADRATURE FILTER CARD ASM	B21916G1		
AR1	Op Amp	816400018	36	LM310H
AR2	Op Amp	816400018	36	LM310H
AR3	Op Amp	816400018	36	LM310H

REFERENCE DESIGNATION	DESCRIPTION	ITHACO PART NUMBER	MANUFACTURER CODE	MANUFACTURER PART NUMBER
S3				
A3	1ST QUADRATURE FILTER CARD ASM	B21916G1		
	CAPACITORS			
C1	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103M
C2	.01μF, 50V, 20%, Cer	811570011	25	8121-050-651-103M
	RESISTORS			
R3	13.3k, 1/8W, 1%, Metflm	817212133		RN60D
R4	3.16K, 1/8W, 1%, Metflm	817211316		RN60D
R5	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
R6	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
R7	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05
A4	CAPACITOR MODULE ASSEMBLY	B21902G2		
	CAPACITORS			
C1	5μF, 50V, 1%, Polycarb	A88104P2	31	A88104P2
C2	.5μF, 100V, 1%, Polycarb	811540041	22	W625B1B504F
C3	.05μF, 100V, 1%, Polycarb	811540043	22	W625B1B503F
C4	.005μF, 200V, 1%, Poly	811560001	97	Style 228
C7	10μF, 50V, 1%, Polycarb	811540067	22	S650DIA106F
C8	1μF, 50V, 1%, Polycarb	811540024	22	W625B1A105F
C9	.1μF, 100V, 1%, Polycarb	811540042	22	W625B1B104F
C10	.01μF, 200V, 1%, Poly	811500002	97	Style 228

REFERENCE DESIGNATION	DESCRIPTION	PART NUMBER	MANUFACTURER CODE	MANUFACTURER PART NUMBER
S3				
A5	INPUT BUFFER CARD ASSEMBLY	B21903G1		
AR1	Op Amp	816400018	36	LM310H
	CAPACITORS			
C1	2μf, 200V, 10%, Myflm	811553013	22	W230B1C-205K
C2	220pf, 1000V, 20%, Cer	811572013	48	10TS-T22
C3	.01μf, 500V, 20%, Cer	811570019	48	5GAS-S10
C4	.01μf, 500V, 20%, Cer	811570019	48	5GAS-S10
	DIODES			
CR1	S I IN4148	818100003		IN4148
CR2	Low Leakage	A86003P1	31	A86003P1
CR3	Low Leakage	A86003P1	31	A86003P1
	TRANSISTORS			
Q1	PNP	818203906		2N3906
Q2	NPN	818203904		2N3904
Q3	Dual N-Chan Fet	A86021P1	31	A86021P1
	RESISTORS			
R1	330 ohm, 1/4W, 5%, Fxd Comp	817007331		RC07
R2	22M, 1/4W, 5%, Fxd Comp	817007226		RC07
R3	825 ohm, 1/4W, 5%, Fxd Comp	817007825		RC07
R4	909 ohm, 1/8W, 1%, Metflm	817210909		RN60D
R5	22 ohm, 1/4W, 5%, Fxd Comp	817007220		RC07
R6	7.5k, 1/8W, 1%, Metflm	817211750		RN60D
R7	51.1 ohm, 1/8W, 1%, Metflm	817219511		RN60D
R8	402 ohm, 1/8W, 1%, Metflm	817210402		RN60D
R9	511 ohm, 1/8W, 1%, Metflm	817210511		RN60D
R10	75 ohm, 1/8W, 1%, Metflm	817219750		RN60D
R11	7.5k, 1/8W, 1%, Metflm	817211750		RN60D
R12	10k, 1/8W, 1%, Metflm	817212100		RN60D
R13	Var, 200 ohm, 10%	817801043	29	66XR200
R14	150 ohm, 1/8W, 5%, Fxd Comp	817000026		RCR05

REFERENCE DESIGNATION	DESCRIPTION	PART NUMBER	MANUFACTURER CODE	MANUFACTURER PART NUMBER
S4	RESISTOR SWITCH ASSEMBLY	C31420G3	31	
	RESISTORS			
R1 A,B,C,D	22.51k, 1/8W, 0.1%, Metflm	817261108	42	PME55
R2 A,B,C,D	18.01k, 1/8W, 0.1%, Metflm	817261110	42	PME55
R3 A,B,C,D	14.07k, 1/8W, 0.1%, Metflm	817261112	42	PME55
R4 A,B,C,D	11.25k, 1/8W, 0.1%, Metflm	817261113	42	PME55
R5 A,B,C,D	9.003k, 1/8W, 0.1%, Metflm	817261114	42	PME55
R6 A,B,C,D	7.145k, 1/8W, 0.1%, Metflm	817261115	42	PME55
R7 A,B,C,D	5.627k, 1/8W, 0.1%, Metflm	817261116	42	PME55
R8 A,B,C,D	4.501k, 1/8W, 0.1%, Metflm	817261117	42	PME55
R9 A,B,C,D	3.573k, 1/8W, 0.1%, Metflm	817261118	42	PME55
R10 A,B,C,D	2.813k, 1/8W, 0.1%, Metflm	817261119	42	PME55
R11 A,B,C,D	2.251k, 1/8W, 0.1%, Metflm	817261120	42	PME55
J1	Connector, BNC	812130110	19	30355-1
J2	Connector, BNC	812130110	19	30355-1
L1	Ferrite Bead	811800014	51	1568
L2	Ferrite Bead	811800014	51	1568
P1	Connector, 16 Pin	812122003	4	26-4100-16P

CODE LIST OF MANUFACTURERS

1	Aerovox
2	Alco Electronic Prod
3	Allen Bradley
4	Amphenol Connector
5	Analog Devices
6	Belden
7	Bourns
8	Buckeye Stamping
9	Bussman Mfg
10	Cambion
11	Cannon, ITT
12	Centralab
13	Cinch Mfg
14	C & K Components
15	Continental– Wirt Elec
16	Corcom
17	Cornell Dubilier Elec
18	CTS
19	Dage Electric
20	Delevan Electronics
21	Dresser Systems
22	Electrocube
23	Electro Motive Mfg
24	Electronics Applications
25	Erie Technological Products
26	Fairchield Semiconductor
27	Federal Screw Prod
28	General Electric
29	Helipot
30	Heyman Mfg
31	ITHACO
32	E F Johnson
33	Litronix
34	Marco–Oak Industries
35	Motorola Semiconductor Prod
36	National Semiconductor
37	Ohmite Mfg
38	Paktron
39	Panduit
40	Pomona Electronics
41	Product Components
42	Pyrofilm
43	RCL Electronics
44	Rembrandt
45	Rogan
46	Schauer Mfg
47	H H Smith
48	Sprague Electric
49	Spectrol Electronics
50	Stancor
51	D M Steward Mfg
52	Switchcraft
53	Teledyne Semiconductor
54	Teledyne Western Wire and Cable
55	Texas Instruments
56	Thermalloy
57	TRW
58	United Transformer
59	Useco
60	Vactec
61	Winchester Electronic
62	Vishay
63	ACI
64	IRC
65	EAL
66	AMP
67	Clarostat Mfg
68	Gould Inc
69	Littlefuse Inc
70	General Illumination
71	Signetrics
72	Semiconductor Cir
73	Statek
74	Bendix
75	Burndy
76	American Handle Sales
77	Varo Semiconductor
78	Dialco
79	Elmenco
80	Amp Incorporated
81	Berg
82	Comp Corp
83	Hewlett–Packard
84	Beckman Helipot
85	Raytheon
86	Intersil
87	A H & H
88	ADC Products
89	Scanbe
90	Drake
91	Victoreen
92	Frost
93	Sigma
94	Becon
95	Microswitch
96	Wavetek
97	Electronic Concepts

TABLE 6.3 CODE LIST OF MANUFACTURERS

Operational Amplifiers

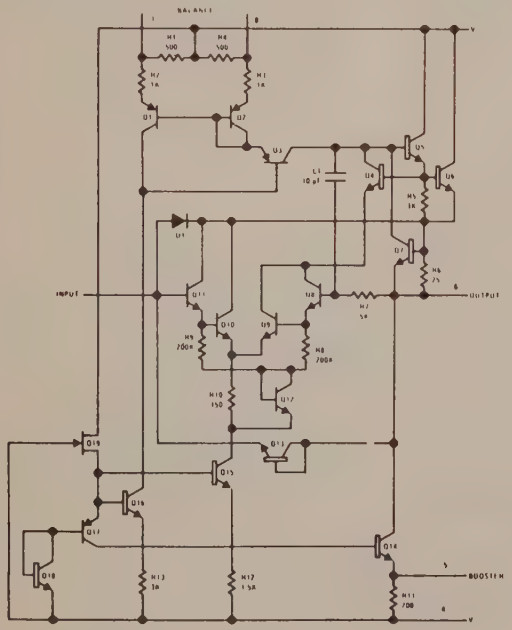
LM310 voltage follower general description

The LM310 is a monolithic operational amplifier internally connected as a unity-gain non-inverting amplifier. It uses super-gain transistors in the input stage to get low bias current without sacrificing speed. Directly interchangeable with 301, 741C and 709C in voltage follower applications, this device has internal frequency compensation and provision for offset balancing. Outstanding characteristics include:

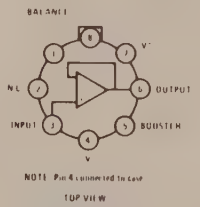
- Input current: 10 nA max. over temperature
- Small signal bandwidth: 20 MHz
- Slew rate: 30V/μs
- Supply voltage range: ±5V to ±18V

The LM310 is useful in fast sample and hold circuits, active filters or as a general-purpose buffer. Further, the frequency response is enough better than standard IC amplifiers that the follower can be included in the feedback loop without introducing instability. It is a plug-in replacement for the LM302 voltage follower, offering lower offset voltage, drift, bias current and noise in addition to higher speed and wider operating voltage range.

schematic** and connection diagrams

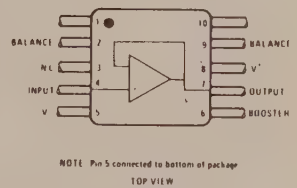


Metal Can



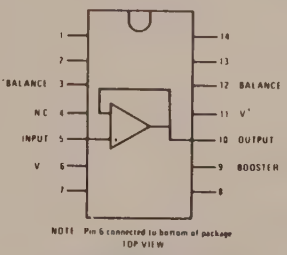
Order Number LM310H
See Package 11

Flat Package



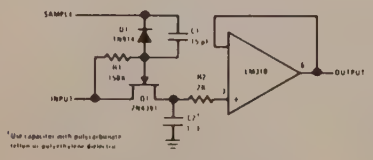
Order Number LM310F
See Package 3

Dual-In-Line

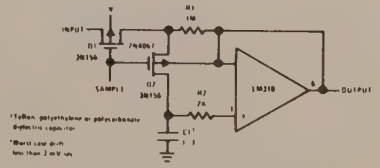


Order Number LM310D
See Package 1

typical applications**



Sample and Hold



Low Drift Sample and Hold*

**Pin connections shown are for metal can.

absolute maximum ratings

Supply Voltage	±18V
Power Dissipation (Note 1)	500 mW
Input Voltage (Note 2)	±15V
Output Short Circuit Duration (Note 3)	Indefinite
Operating Temperature Range	0°C to 70°C
Storage Temperature Range	−65°C to 150°C
Lead Temperature (Soldering, 10 sec)	300°C

electrical characteristics (Note 4)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Input Offset Voltage	$T_A = 25°C$		2.5	7.5	mV
Input Bias Current	$T_A = 25°C$		2.0	7.0	nA
Input Resistance	$T_A = 25°C$	10^{10}	10^{12}		Ω
Input Capacitance			1.5		pF
Large Signal Voltage Gain	$T_A = 25°C$, $V_S = ±15V$ $V_{OUT} = ±10V$, $R_L = 8K\Omega$	0.999	0.9999		V/V
Output Resistance	$T_A = 25°C$		0.75	2.5	Ω
Supply Current	$T_A = 25°C$		3.9	5.5	mA
Input Offset Voltage				10	mV
Offset Voltage Temperature Drift			10		μV/°C
Input Bias Current				10	nA
Large Signal Voltage Gain	$V_S = ±15V$, $V_{OUT} = ±10V$ $R_L = 10K\Omega$	0.999			V/V
Output Voltage Swing (Note 5)	$V_S = ±15V$, $R_L = 10K\Omega$	±10			V
Supply Voltage Rejection Ratio	$±5V \leq V_S \leq ±18V$	70	80		dB

Note 1: The maximum junction temperature of the LM310 is 85°C. For operating at elevated temperatures, devices in the TO-5 package must be derated based on a thermal resistance of 150°C/W, junction to ambient, or 45°C/W, junction to case. For the flat package, the derating is based on a thermal resistance of 185°C/W when mounted on a 1/16-inch-thick epoxy glass board with ten, 0.03-inch-wide, 2-ounce copper conductors. The thermal resistance of the dual-in-line package is 100°C/W, junction to ambient.

Note 2: For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.

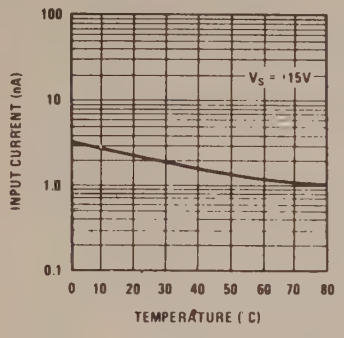
Note 3: Continuous short circuit is allowed for case temperatures to 70°C and ambient temperatures to 55°C. It is necessary to insert a resistor greater than 2 kΩ in series with the input when the amplifier is driven from low impedance sources to prevent damage when the output is shorted.

Note 4: These specifications apply for $±5V \leq V_S \leq ±18V$ and $0°C \leq T_A \leq 70°C$, unless otherwise specified.

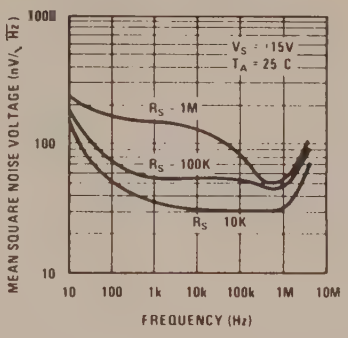
Note 5: Increased output swing under load can be obtained by connecting an external resistor between the booster and V^- terminals. See curve.

typical performance characteristics

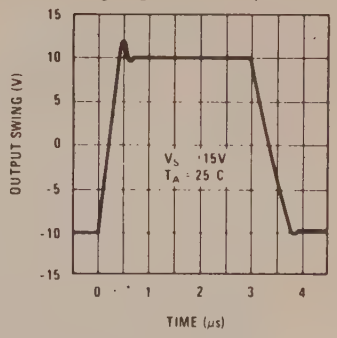
Input Current



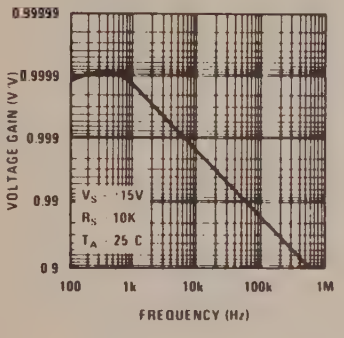
Output Noise Voltage



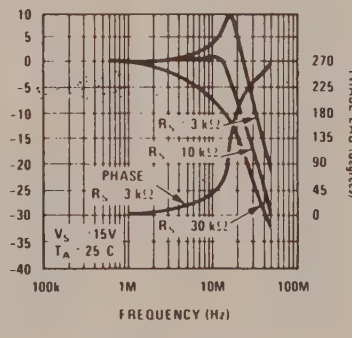
Large Signal Pulse Response



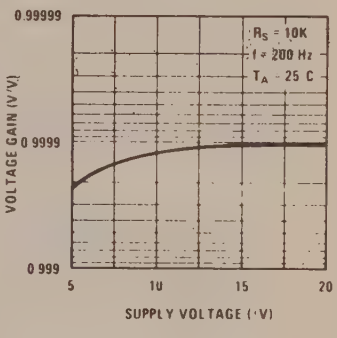
Voltage Gain



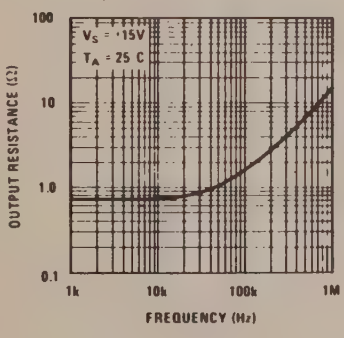
Voltage Gain



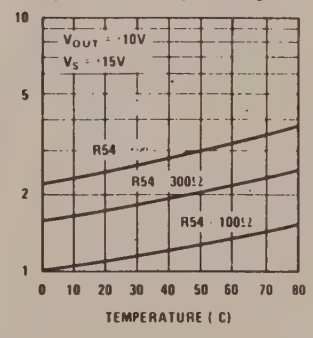
Voltage Gain



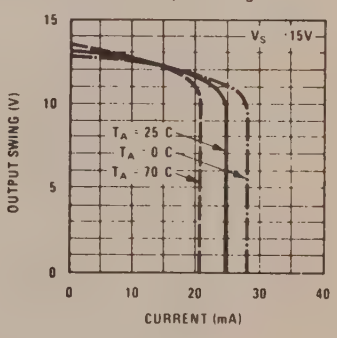
Output Resistance



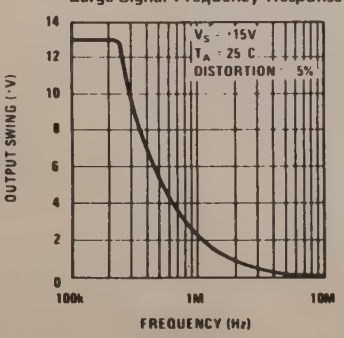
Symmetrical Output Swing



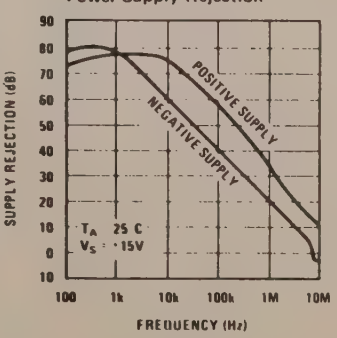
Positive Output Swing



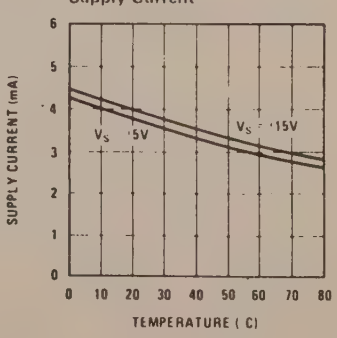
Large Signal Frequency Response

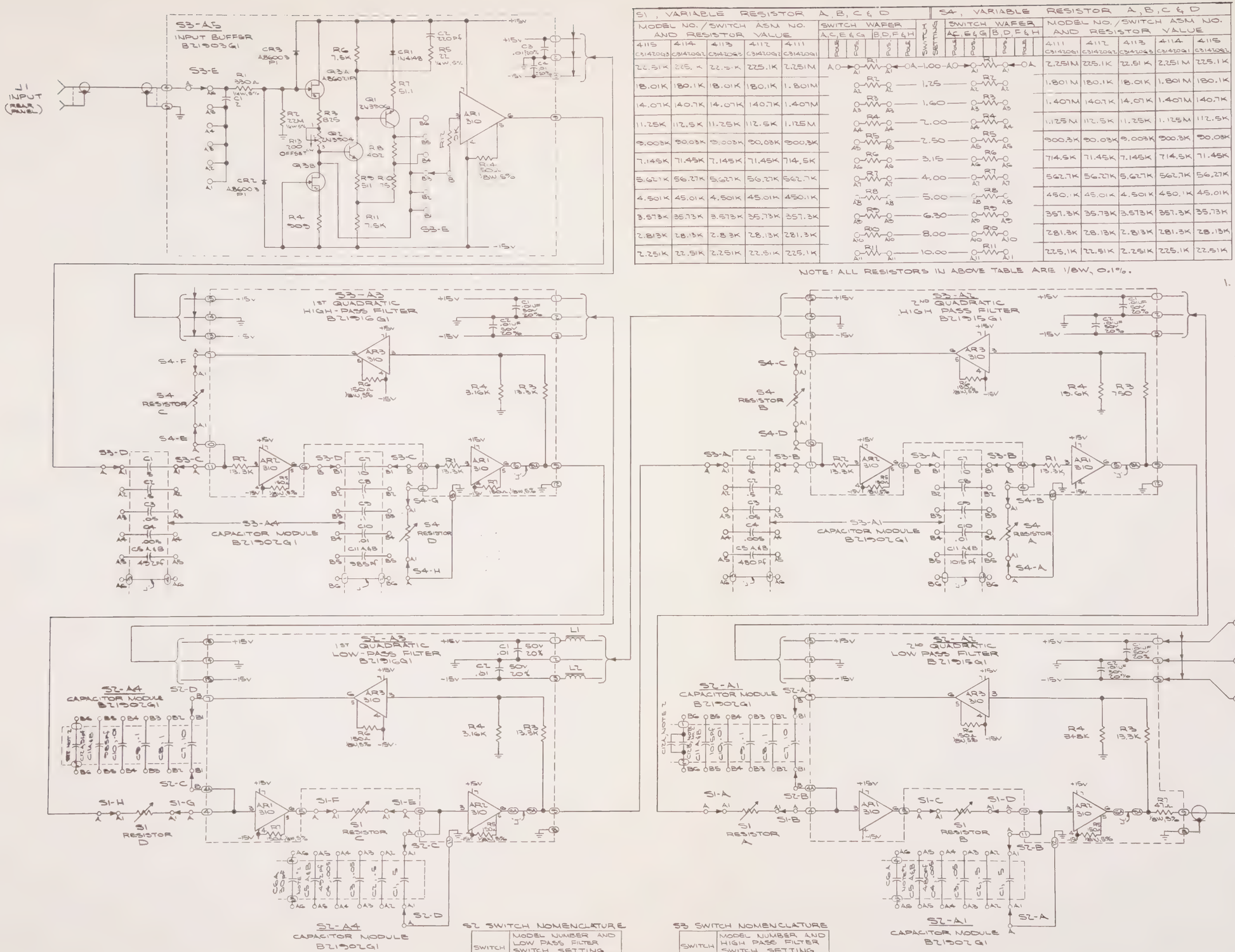


Power Supply Rejection



Supply Current





S1, VARIABLE RESISTOR A, B, C & D					S4, VARIABLE RESISTOR A, B, C & D				
MODEL NO./SWITCH ASM NO. AND RESISTOR VALUE					SWITCH WAFER A,C,E & G / B,D,F & H; SWITCH SETTING	MODEL NO./SWITCH ASM NO. AND RESISTOR VALUE			
4115 C3142093	4114 C3142092	4113 C3142093	4112 C3142092	4111 C3142091		4111 C3142091	4112 C3142092	4113 C3142093	4114 C3142092	4115 C3142093
22.51K	225.K	22.51K	225.1K	2.251M	A0 — R1 — 0A	2.251M	225.1K	22.51K	2.251M	225.1K
18.01K	180.1K	18.01K	180.1K	1.801M	1.25 — R2 — A1	1.801M	180.1K	18.01K	1.801M	180.1K
14.07K	140.7K	14.07K	140.7K	1.407M	1.60 — R3 — A2	1.407M	140.7K	14.07K	1.407M	140.7K
11.25K	112.5K	11.25K	112.5K	1.125M	2.00 — R4 — A3	1.125M	112.5K	11.25K	1.125M	112.5K
9.003K	90.03K	9.003K	90.03K	900.3K	2.50 — R5 — A4	900.3K	90.03K	9.003K	900.3K	90.03K
7.145K	71.45K	7.145K	71.45K	714.5K	3.15 — R6 — A5	714.5K	71.45K	7.145K	714.5K	71.45K
5.627K	56.27K	5.627K	56.27K	562.7K	4.00 — R7 — A6	562.7K	56.27K	5.627K	562.7K	56.27K
4.501K	45.01K	4.501K	45.01K	450.1K	5.00 — R8 — A7	450.1K	45.01K	4.501K	450.1K	45.01K
3.573K	35.73K	3.573K	35.73K	357.3K	6.30 — R9 — A8	357.3K	35.73K	3.573K	357.3K	35.73K
2.813K	28.13K	2.813K	28.13K	281.3K	8.00 — R10 — A9	281.3K	28.13K	2.813K	281.3K	28.13K
2.251K	22.51K	2.251K	22.51K	225.1K	10.00 — R11 — A10	225.1K	22.51K	2.251K	225.1K	22.51K

NOTE: ALL RESISTORS IN ABOVE TABLE ARE 1/8W, 0.1%.

NOTES:

1. UNLESS OTHERWISE SPECIFIED:
   a. RESISTOR VALUES ARE IN OHMS
   b. CAPACITOR VALUES ARE IN MF
   c. CAPACITOR TOL'S ARE ± 1%
   d. CAPACITORS ARE 50V MIN.
   e. RESISTORS ARE 1/8W, 1%

2. CAPACITOR NUMBERS SUFFIXED A & B ARE VALUES OBTAINED BY PARALLEL COMPONENTS.

   CAPACITORS S2A1-C6A, S2A1-C12A&B S2A4-C6A AND S2A4-C12A ARE TRIM CAPACITORS AND THERE VALUES VARY BETWEEN FILTER MODELS, THERE VALUES ARE AS FOLLOWS:

MODEL NO.	CAPACITOR & VALUE			
	S2A1-C6A	S2A1-C12A&B	S2A4-C6A	S2A4-C12A
4111	27pf	122pf	30pf	91pf
4112	27pf	122pf	30pf	91pf
4113	30pf	110pf	30pf	91pf
4114	27pf	122pf	30pf	91pf
4115	30pf	110pf	30pf	91pf

3. FOR S2 SWITCH ASM SEE C3135GG1; FOR S3 SWITCH ASM SEE C3146GG1.

S2 SWITCH NOMENCLATURE

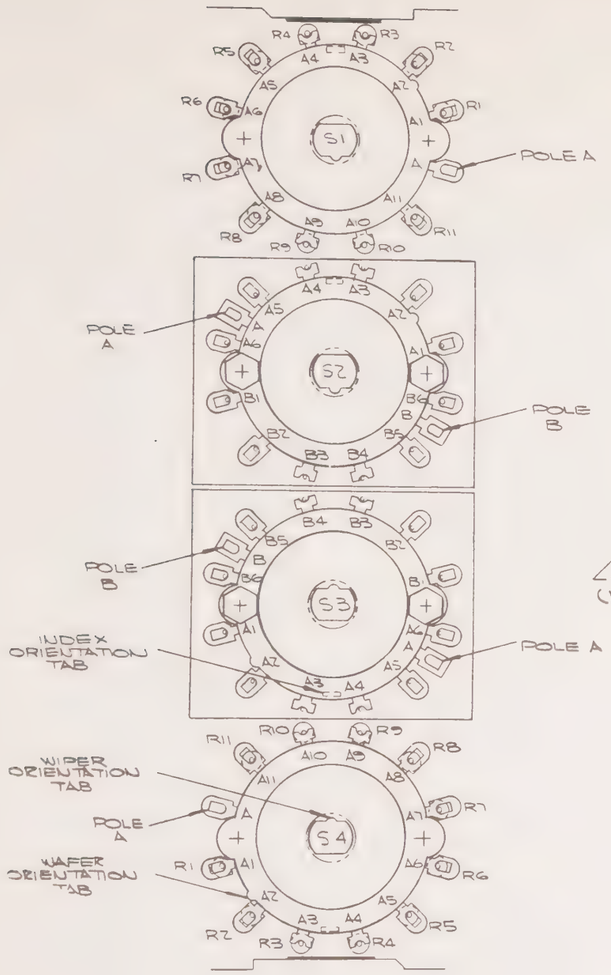
SWITCH POSITION	MODEL NUMBER AND LOW PASS FILTER SWITCH SETTING		
	4111	4112 & 4114	4113 & 4115
A1 & B1	X.01	X.1	X1
A2 & B2	X.1	X1	X10
A3 & B3	X1	X10	X100
A4 & B4	X10	X100	X1K
A5 & B5	X100	X1K	X10K
A6 & B6	X1K	X10K	X100K

S3 SWITCH NOMENCLATURE

SWITCH POSITION	MODEL NUMBER AND HIGH PASS FILTER SWITCH SETTING		
	4111 & 4114	4112 & 4115	4113
A1 & B1	X.01	X.1	X1
A2 & B2	X.1	X1	X10
A3 & B3	X1	X10	X100
A4 & B4	X10	X100	X1K
A5 & B5	X100	X1K	X10K
A6 & B6	OUT	OUT	OUT

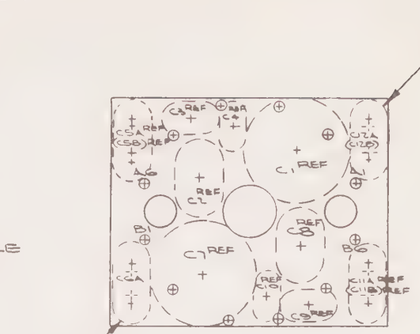
ITHACO DWG F50019, REV B, 12/75

FIGURE 7.1
4110 SERIES
SCHEMATIC

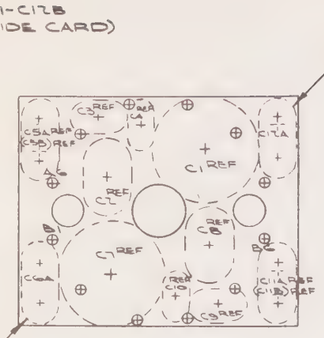


VIEW AT "A"

SHEET 2



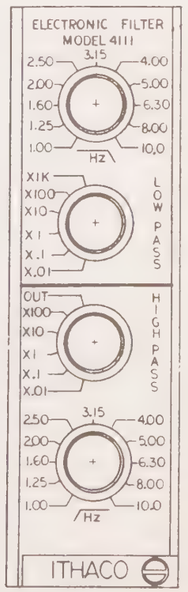
VIEW AT 'A' OF S2-A1



(G1) MODEL 4111
AS SHOWN

(G2) MODEL 4112
SAME AS G1 EXCEPT:
A.) S2 IS MARKED X.1, X1, X10, X100, X1K & X10K
B.) S3 IS MARKED X.1, X1, X10, X100, X1K & OUT
C.) PARTS LIST VARIES FOR ITEMS S1, S2A1-C6A & C12B, S2A4-C6A & C12A, S4, AND FRONT PANEL ITEM 4.

(G3) MODEL 4113
SAME AS G1 EXCEPT:
A.) S2 IS MARKED X1, X10, X100, X1K, X10K & X100K
B.) S3 IS MARKED X1, X10, X100, X1K, X10K & OUT
C.) SAME AS G2



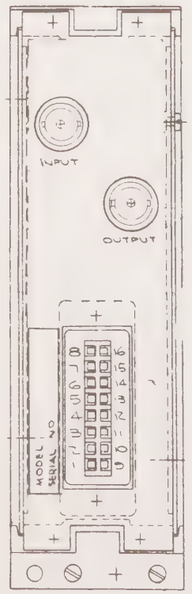
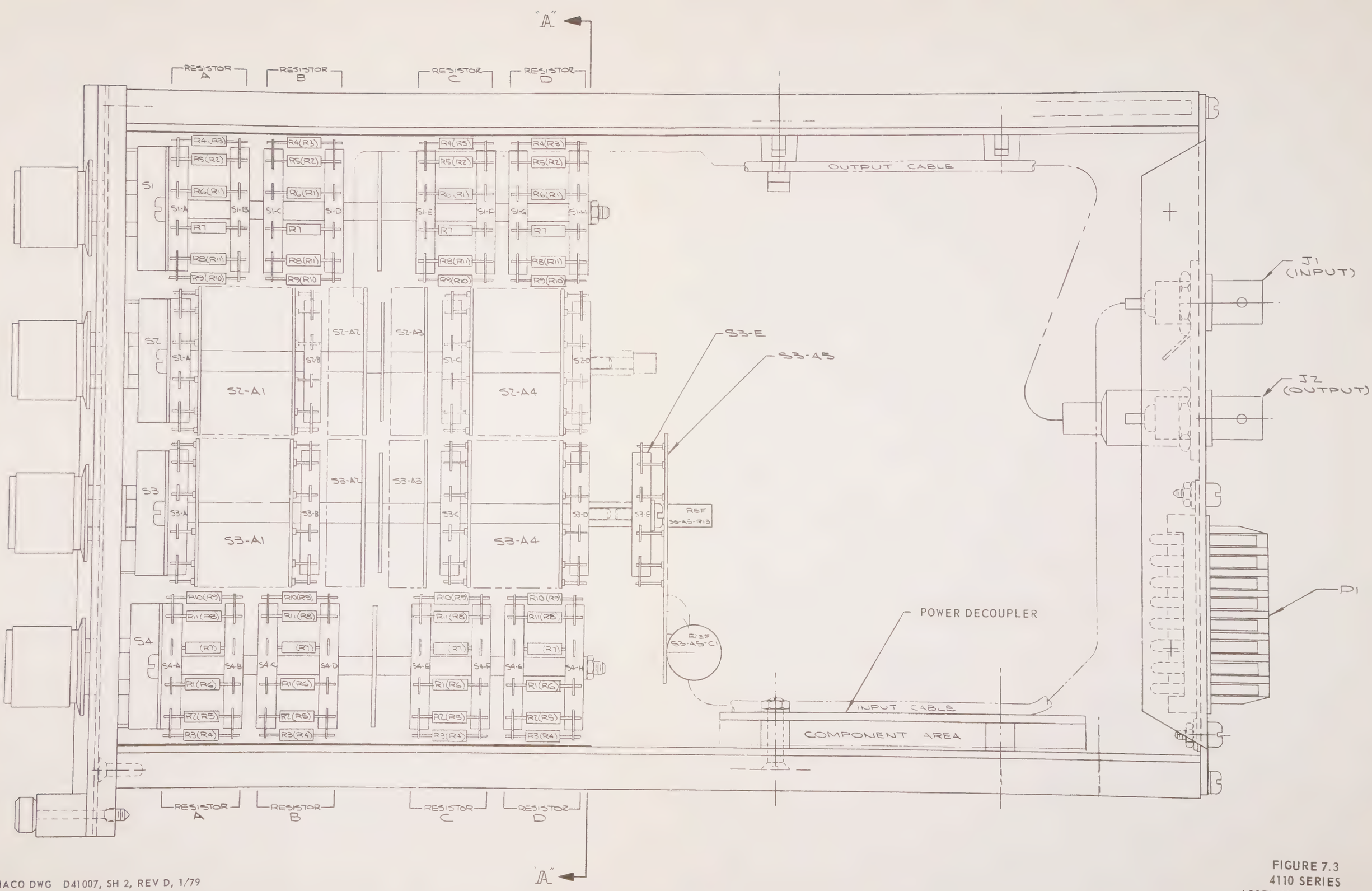
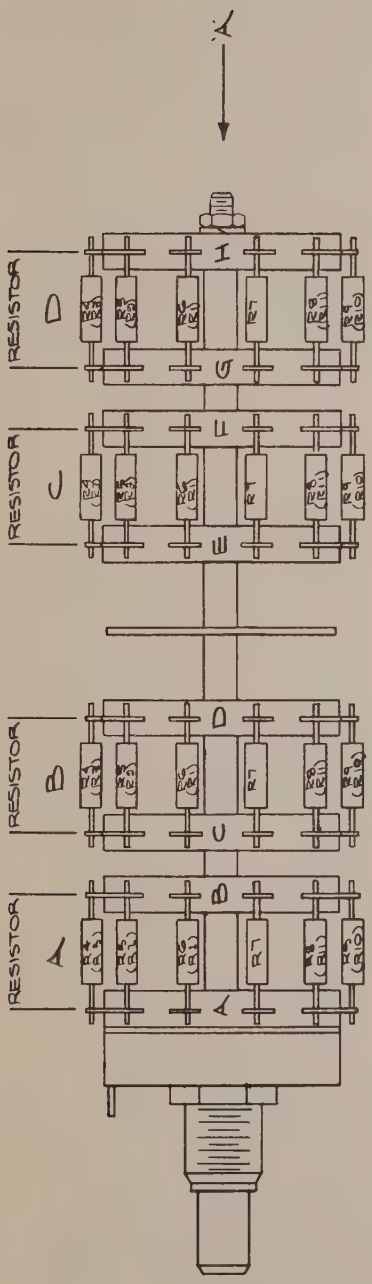


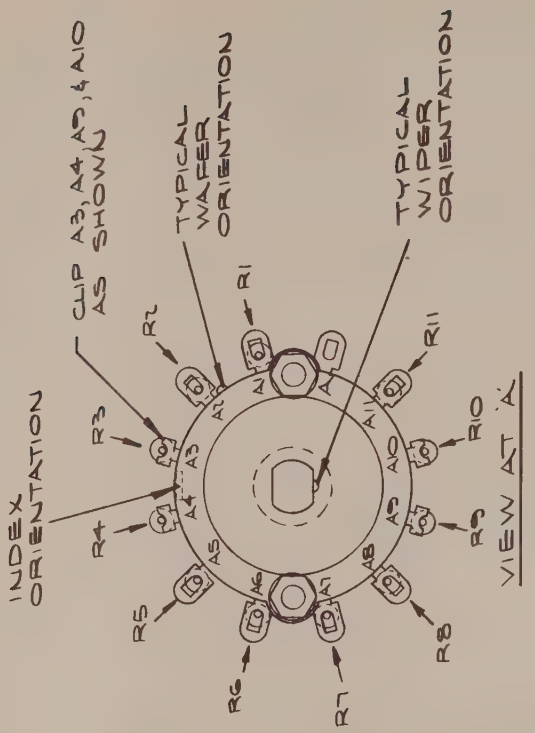
FIGURE 7.2
4110 SERIES
ASSEMBLY – SHEET 1



ITHACO DWG D41007, SH 2, REV D, 1/79

FIGURE 7.3
4110 SERIES
ASSEMBLY – SHEET 2





RESISTOR ASSEMBLY CHART

ITEM	FROM	TO	ITEM	FROM	TO
R1-A	A-A1	B-A1	R1-C	E-A1	F-A1
R2-A	A-A2	B-A2	R2-C	E-A2	F-A2
R3-A	A-A3	B-A3	R3-C	E-A3	F-A3
R4-A	A-A4	B-A4	R4-C	E-A4	F-A4
R5-A	A-A5	B-A5	R5-C	E-A5	F-A5
R6-A	A-A6	B-A6	R6-C	E-A6	F-A6
R7-A	A-A7	B-A7	R7-C	E-A7	F-A7
R8-A	A-A8	B-A8	R8-C	E-A8	F-A8
R9-A	A-A9	B-A9	R9-C	E-A9	F-A9
R10-A	A-A10	B-A10	R10-C	E-A10	F-A10
R11-A	A-A11	B-A11	R11-C	E-A11	F-A11
R1-B	C-A1	D-A1	R1-D	G-A1	I-A1
R2-B	C-A2	D-A2	R2-D	G-A2	I-A2
R3-B	C-A3	D-A3	R3-D	G-A3	I-A3
R4-B	C-A4	D-A4	R4-D	G-A4	I-A4
R5-B	C-A5	D-A5	R5-D	G-A5	I-A5
R6-B	C-A6	D-A6	R6-D	G-A6	I-A6
R7-B	C-A7	D-A7	R7-D	G-A7	I-A7
R8-B	C-A8	D-A8	R8-D	G-A8	I-A8
R9-B	C-A9	D-A9	R9-D	G-A9	I-A9
R10-B	C-A10	D-A10	R10-D	G-A10	I-A10
R11-B	C-A11	D-A11	R11-D	G-A11	I-A11

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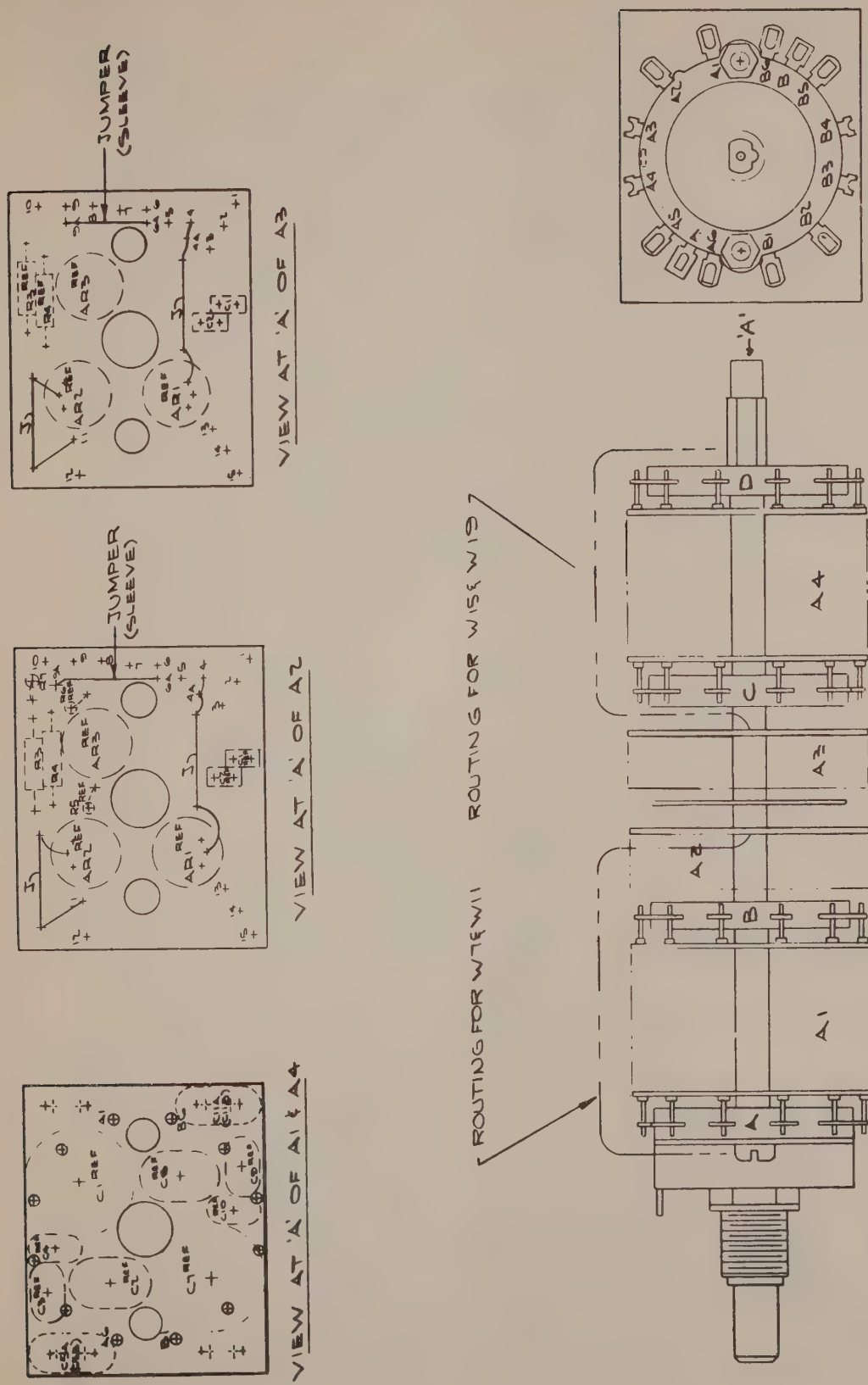
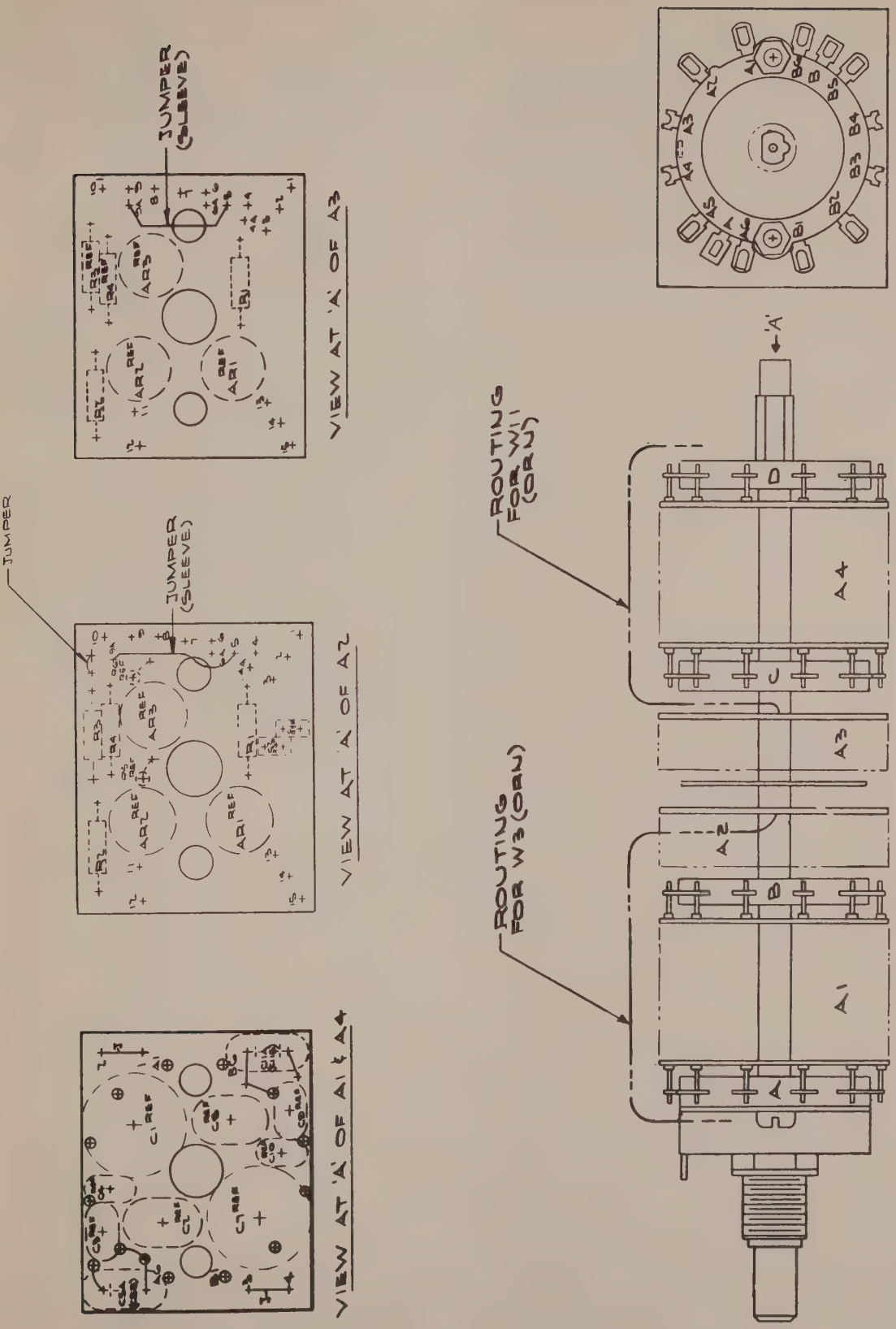
FIGURE 7.4 RESISTOR SWITCH ASSEMBLY (S1 AND S4) – 4110 SERIES



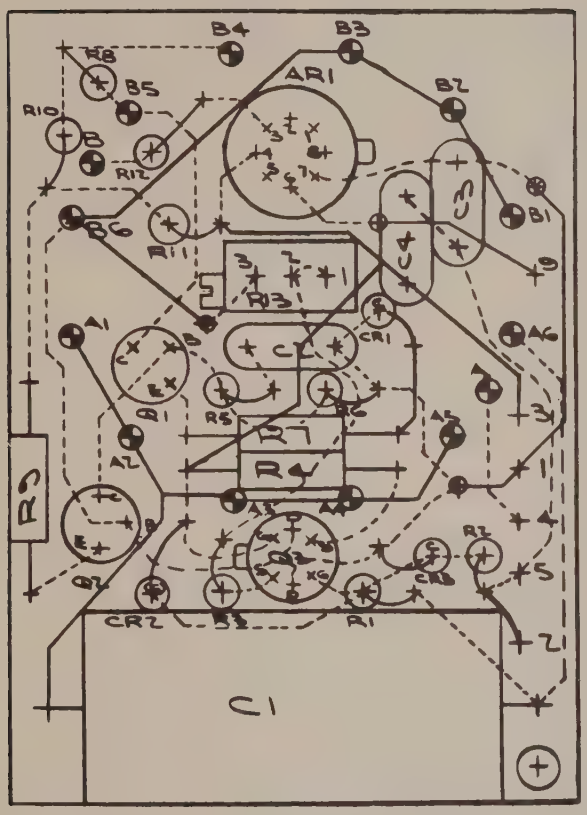
ITHACO DWG C31399, REV D, 1/79

FIGURE 7.5 LPF CAPACITOR SWITCH ASSEMBLY (S2) – 4110 SERIES



ITHACO DWG C31460, REV E, 1/79

FIGURE 7.6 HPF CAPACITOR SWITCH ASSEMBLY (S3) – 4110 SERIES



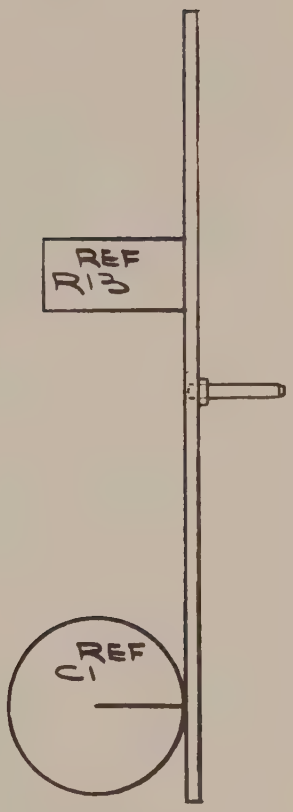


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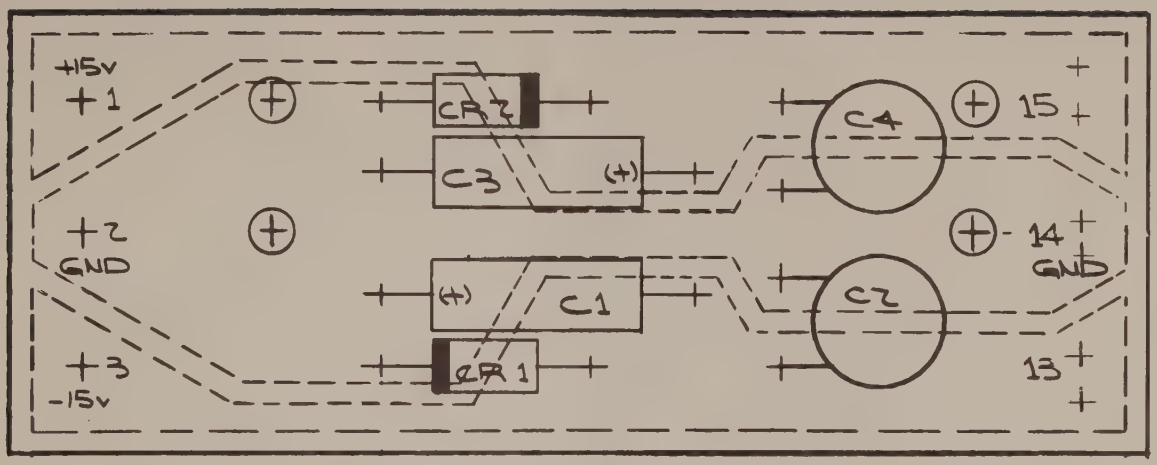
FIGURE 7.7 INPUT BUFFER ASSEMBLY – 4110 SERIES



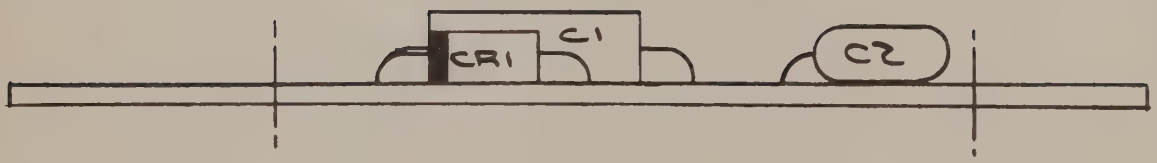


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FIGURE 7.8 POWER DECOUPLING ASSEMBLY – 4110 SERIES

WARRANTY

ITHACO Inc. warrants each instrument to be free of defects in material and workmanship for a period of one year after shipment to the original purchaser; batteries are specifically excluded. Liability under this warranty is limited to repairing or adjusting any instrument returned to the factory for that purpose. The warranty of this instrument is void if the instrument has been modified other than in accordance with written instructions from ITHACO, or if defect or failure is judged by ITHACO to be caused by abnormal conditions of operation, storage or transportation.

This warranty is subject to verification by ITHACO, that a defect or failure exists, and to compliance by the original purchaser with the following instructions:

1. Before returning the instrument, notify ITHACO with full details of the problem; include model number and serial number of the instrument involved.

2. After receiving the above information, ITHACO will give you shipping instructions or service instructions. After receipt of shipping instructions, ship the instrument to ITHACO. Full liability for damage during shipment is borne by the purchaser. It is recommended that instruments shipped to us be fully insured and packed surrounded by at least 2 inches of shock-absorbing material.

ITHACO reserves the right to make changes in design at any time without incurring any obligation to install same on units previously purchased.

This warranty is expressly in lieu of all other obligations or liabilities on the part of ITHACO, and ITHACO neither assumes, nor authorizes any other person to assume for it, any liability in connection with the sales of ITHACO instruments.

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